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DESIGN DEFINITION STUDY REPORT. FULL CREW INTERACTION SIMULATOR--ETC(U)

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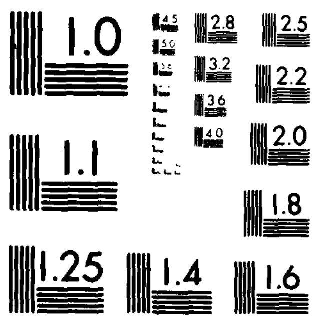

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Design Definition Study Report

Full Crew Interaction Simulator

Laboratory Model (FCIS-LM) Device X17B7

prepared for

Naval Training Equipment Center
Orlando, Florida

Link
A DIVISION OF THE SINGER COMPANY

Report No: NAVTRAEQUIPCEN 77-C-0185-0001
LR-895

DESIGN DEFINITION STUDY REPORT

FULL CREW INTERACTION SIMULATOR-LABORATORY MODEL

(DEVICE X17B7)

VOLUME VI - TRAINING SYSTEMS

Link Division, The SINGER COMPANY
Binghamton, New York 13902

FINAL
June 1978

Prepared for:
NAVAL TRAINING EQUIPMENT CENTER
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SECTION XI

11. TRAINING SYSTEMS STUDY AND CONCEPT FORMULATION

Training systems comprise those systems that are not associated with direct simulation of the vehicle or the environment, but are needed to complete the total trainer requirement. They include:

- Trainer Power System
- Trainer Maintenance System
- Trainer Instructional System
- Trainer Computational System

Of these, only the trainer instructional and computational systems require extensive study to formulate a design approach for the FCIS-LM device.

11.1 Instructional System

11.1.1 Instructor Requirements. Instructor tasks involve the following basic functions:

a. Initializing and controlling training exercises

b. Monitoring and evaluating trainee (crew) performance

c. Modifying the training exercise, as necessary

d. Briefing and debriefing trainees (crews)

e. Collecting, controlling data and setting up experiments to be performed in the simulator.

The M60A3 Task Analysis and resultant Training Requirements Analysis and Experimental Requirements Analysis (Sections 4, 5, and 6) form the basis from which instructor loads, manning, display and control requirements are derived. Those monitoring,control and evaluation functions which are impossible, inappropriate or not cost effective to automate, will be assigned to the instructor. Once these functions are determined, examining them in relation to human perceptual, conceptual and motor capabilities and characteristics will help determine the manning loads and instructor placement requirements for the various training tasks.

11.1.1.1 Simulated Tank Systems. The instructor requires the capability to set up, monitor and modify the following simulated tank systems:

a. Tank and turret position, heading, and ground speed (including acting as driver).

b. Fuel and oil systems pressures and levels.

c. Engine temperature and rpm.

d. Transmission selection.

e. Brake system.

f. Main gun orientation, breech movement, safety control.

g. .50 caliber loading and performance.

h. 7.62 coaxial machine gun loading

i. Sighting,ranging,and firing system readings and performance.

j. Radio and intercom system selection, volume and static or jamming.

k. Associated aural cue, vibration.

l. Malfunctions as described in Section 11.1.7.2.

11.1.1.2 Simulated Operating Environment. The instructor requires the capability to set up, monitor, and modify the following aspects of the simulated operating environment:

a. Visibility - both direct viewing and using special optics and viewing devices.

b. Surface characteristics - audiofrictional and vibratory/motion cues associated with various types of terrain. (Specifically pavement, soil, gravel, and amplitude and frequency of perturbations in these surfaces).

c. Monitor only: Orientation and location of significant programmed contours, foliation, terrain features and fixed cultural features in the operating area of the simulated (own) tank.

d. Location, direction, type of vehicle, speed of movement and reaction to the simulated tank of up to 5 moving threats and 15 stationary threats. The instructor must know when threats move into line of sight positions, signifying the earliest point at which an engagement might begin.

11.1.1.3 Advanced Training Features. The instructional system must provide sufficient control and display capabilities to allow the appropriate use of the following advanced training features:

a. Malfunctions:

1. Review malfunctions by system.

2. Insert malfunctions.

3. Delete malfunctions.

4. Delete all active malfunctions.

5. Monitor all active malfunctions by number and description.

6. Inhibit preprogrammed malfunctions.

b. Weapons:

1. Select weapon malfunctions.

2. Display and control threat and friendly firing and reaction to the own tank (manually or automatically).

3. Select target to be engaged or target sequence.

4. View map, visual, and alphanumeric/graphic displays of gunnery performance.

c. Hardcopy: Store "snapshots" of the alphanumeric/map displays.

d. Map Control:

1. Display appropriately scaled tactical contour maps with own tank and threat track.

2. Erase ground track.

e. Reverse/Advance Multiple Page CRT Displays (e.g., malfunctions).

f. Data Clear - Clear all data accumulated during a previous training session and reinitialize to a clean condition.

g. Freeze the entire training problem and monitor when a freeze condition exists.

h. Select demonstrations, preprogrammed test exercises, or record/playback sections. Thirty minutes of record/

playback is specified. The best method would be to divide the total capacity into engagement replays for instructor selection, for corrective instruction, or positive reinforcement, or for instructor debriefing. Segments of one minute should be sufficient for properly recording an engagement.

i. Adaptive training. In order to provide more efficient crew training, the instructor will require the capability to adaptively alter the following training features.

1. Simulated tank system characteristics as discussed in Section 11.1.1.1.

2. Sophistication of threat tactics.

3. Reaction time and accuracy of threat fire.

4. Kill radius of own tank rounds.

5. Apparent velocity, smoke trackability and other factors affecting own round sensing.

6. Crew feedback on threat positions, movement, strength and tactics. (For example: Perhaps the tank commander might be shown a real-time tactical terrain map during early tactics familiarization training).

7. Level of simulated tank dynamics fidelity, or degrees of freedom of motion.

8. Field of view and resolution degradation as the crew becomes more skilled.

11.1.1.4 Crew Performance Monitoring and Evaluation. During training operations in the FCIS device, the instructor(s) must be capable of the following functions:

a. Monitor, analyze and evaluate individual crew member's actions and reactions (including normal and emergency procedures and intracrew reactions to a variety of terrain and threat stimuli)

b. Monitor, analyze and evaluate coordinated crew actions and reactions (including normal and emergency procedures and a variety of friendly force, terrain and threat force stimuli)

c. Adaptively vary the tactical environment to tax the crew without overwhelming them - to locate and eliminate individual crew weaknesses. This will require:

1. Capability to observe and identify any weak point in individual or crew actions.

2. Knowledge of type and location (including when detection and kill positions are reached) of all friendly and threat forces.

3. Capability to coordinate friendly armor and artillery fire.

4. Capability to use visual scene and dynamic tactical maps to determine best routes, best firing positions, best offensive and defensive actions and reactions from which to evaluate and modify crew headwork and actions.

d. Make use of advanced training capabilities, especially playback and hardcopy, in monitoring and evaluation tasks.

e. View gunner's sight picture.

f. Initiate engagement timing sequence when line-of-sight with target established, and record the time of the following events:

1. Line of sight reached

2. Threat sighted by crew and identified

3. Commander's lay complete

4. Target acquired

5. Proper round loaded and ready

6. Driver actions complete or proper

7. First round away

8. Round sensed

9. Corrections complete

10. Subsequent round away

11.1.1.5 Additional Control-Display Requirements. The following controls must be provided at each instructor station and also at the driver and fighting stations:

a. EMERGENCY STOP/POWER CUTOFF to the entire complex

b. MOTION ON/OFF control/indication

c. FREEZE control/indication

d. Emergency intercommunications with each other and the computer complex.

11.1.1.6 Locus and Manning. These requirements are best determined experimentally, but in the absence of experimental evidence, it is recommended that worst-case conditions be allowed for. This would be during high-density tactical engagements when the automatic performance monitoring systems would be fully employed, and both the turret crew and the driver actions, coordination and visual scene reactions, would need to be carefully monitored to identify those errors in judgment and inefficiencies that cost vital split seconds during battle engagements. Visual contact with the crew is the most efficient and accurate method of detecting those weaknesses.

An additional instructor is required at a remote location to monitor and control the complex, battle environment, especially the movement and fire of a highly mobile threat force of battle tanks. Thus, during training, as many as three instructor/observors might be required, a main tactical controller and an instructor/observer at each crew training station. During certain experiments, a fourth individual will be required to observe the instructional techniques or provide additional real-time problem modification inputs.

11.1.2 Experimental Requirements. Additional display and control features to those defined for the instructor are necessary to perform the desired experimental functions of the FCIS-LM device. This is primarily due to the experimenter's need for a more powerful analysis tool, and also to the fact that in some instances, the experimenter role will be met by the instructor. The need to operate the FCIS-LM device solely with an instructor/experimenter is defined by the set of experiments in which the "instructor" plays a passive role and where experimental results are identified and collected by the computational system.

In the following typical experiments, it is assumed that the data collected during the experiment will be processed and analyzed at the conclusion of the experiment.

a. Determining the importance and impact in the use of motion on task performance.

b. Reassessment of crew response time as related to visual cue enhancement.

c. Evaluating capacity of FCIS-LM device for conducting training in specific tasks.

In this group of experiments, the issue is not whether the crew achieves the desired level of proficiency, but whether variations in simulation fidelity can be relevant to training at all. Therefore, data required to make these evaluations must be quantified and collected as part of the simulation system.

The specific needs of the experimenter, after the problem has been initiated and the majority of his instructor's role tasks are completed, are analytical in nature. These needs can be categorized as (a) instantaneous data either in raw or processed form and (b) trend data. Instantaneous data can simply be current values of variables in the simulated problem; measures such as elapsed time since target acquisition, and the like. They may also take the form of standard statistical measures such as RMS, maximum deviation, power spectral density, etc. The other class of data is time history or trend data. Trending data can relate to either raw simulation parameters or processed data.

For this type of information to be available to the experimenter, the control station must be capable of performing two specific functions. The first is to access in real-time, any piece of information residing in the simulation data pool and display it in meaningful format at the control station. The second function required is the ability to display this same data in time history or X-Y format (where x, y occur at the same instant in time). The equipment at the control station should, if feasible, have the capability to store past values of the data, rather than retain it in computer memory, since this latter function would require excessive amounts of storage space and impose an unnecessary requirement on computational system equipment.

An adjunct capability to the display of data pool information is the need to alter certain simulation variables from the external control console. The combination of this capability with the display requirement leads to the need for the experimenter to be able to generate either real-time displays or trend displays on-line rather than live with preconceived data display requirements. This flexibility will provide the experimenter with a powerful tool to be used during the conduct of experiments. It will also allow him to reformat display data to be monitored without interrupting the experiment, and look at new data in conjunction with other data previously defined as relevant.

Another experimental requirement is in pre-defining or pre-formulating the experiment to be conducted. This must include the capability to establish the problem, automatically modify certain aspects (such as insertion of failures), change environmental conditions, alter experimental conditions, and so on. The system should operate on action/reaction cues, where computer software monitors the simulator state and takes prescribed action when certain conditions are met. This system must be activated with a minimum of instructor or experimenter action and should be totally automatic once initiated.

In summary, the experimenter must have the following capabilities:

a. Perform all instructor tasks.

b. Ability to access control and display any simulator variable.

c. Display trend data.

d. Have the ability to alter real-time display formats on-line without interrupting experiments.

e. Define the trend data to be displayed at the experimenter console on-line during experimentation.

f. Develop, initiate, and alter pre-formulated experiments on-line.

11.1.3 INSTRUCTOR STATION

11.1.3.1 Instructor Driving Provisions. The statement of work specifies detailed requirements for instructor driving controls when operating the simulated vehicle in an override mode. During the study, it was determined that providing a duplicate set of tank driving controls represented the least cost effective approach. Although duplicate controls would be familiar to the instructor, the burden of operating the vehicle just like the real world would distract the instructor from his primary role as observer and teacher. In addition, instructor controls to meet the SOW requirements of vehicle operation from startup to shutdown, provide no training benefit. Therefore, a simplified approach to instructor operation and control is considered adequate and several approaches have been identified.

11.1.3.1.1 Keyboard/Display Page Approach. This method would utilize the display system and function keyboard for driving control. The display page would contain both control and status parameters as shown in Figure 11-1. When instructor override is selected (by editing the display page), the engine would be started automatically. Using the function keys: FORWARD, REVERSE, LEFT TURN and RIGHT TURN, the instructor can control the direction of the simulated vehicle while referencing the visual scene on his visual repeater. Speed would be controlled by a potentiometer. A neutral-steer turn would be executed by setting the speed control to zero and selecting the function key for the desired turn direction. Deletion of instructor override mode would shut down the engine.

11.1.3.1.2 Joystick/Display Page. This approach to instructor driving control would utilize a joystick and display page. The display page operation would be identical to that described in the Keyboard/Display Page Approach. The joystick would provide directional and speed control with speed proportional to the displacement of the joystick. Activation of a joystick button would initiate a neutral-steer turn. Releasing the

ENGINE	
GEAR SHIFT POSITION	X
BRAKES	XX PSI
SPEEDOMETER	XX MPH
GROUND SPEED	XX MPH
MISCELLANEOUS SYSTEMS	
TURRET POSITION TO HULL	XXX
GUN ELEVATION (REFERENCE TO HULL)	XX
HYDRAULIC GAUGE	XXXX
GUEL QUANTITY	XXXX
MASTER SWITCH	XXX
TURRET HYDRAULIC POWER SWITCH	XXX
TURRET SEAL	XXXXXX
GAS PARTICULATE	XXX
DRIVING CONTROL	
INSTRUCTOR OVERRIDE	XXX

Figure 11-1 TYPICAL SYSTEM STATUS PAGE

joystick returns it to neutral center position. To permit the instructor to maintain a desired track for a period of time, without requiring him to continuously hold the joystick, a HOLD function switch would be provided. When this switch is activated, the direction and speed will be maintained and the joystick may be released.

11.1.3.1.3 Trackball/Display Page. With this approach,a trackball and display page would be used. Once again the display page would be the same as for the previous approaches. As with the joystick, the trackball would provide both direction and speed control. The trackball would not return to neutral when released,so it could be left in any position to maintain a desired track. A function switch would be provided to initiate a neutral-steer turn.

11.1.3.1.4 Steering Bar/Display Page. In this approach a steering T-bar, speed control, and display page would be combined to provide instructor driving control. The steering bar would be a handsize replica of the tank steering control with a button on each end for neutral-steer turn control. The T-bar would provide directional control while speed control would be implemented with a potentiometer or function key. The display page would be identical to that used in the other approaches.

11.1.3.2 Vehicle Position Chart (VPC). Several systems can be formulated to instantaneously display the position of the own tank and tactical targets with respect to fixed cultural and geographic scenario elements. The basic requirement is to provide relative position with reference to own tank position on topographical map plates. One method would be to use an X-Y recorder (pen and ink recorder). Fixed geographical and cultural information can be portrayed in this manner, using either real-world paper maps or slides of these maps. Another method would employ a CRT type terminal. This alternative has two possible subsolutions. The first: using a stroke writing or random scan terminal where all information portrayed is generated by the simulator computer and drawn by the CRT display system; the second: using a raster type (home TV) display system. Both of these systems would permit the superimposing of videotape images of fixed maps and the positioning of moving targets and owntank via computer generated graphics symbology. Still another way to solve this problem is the use of a plasma or flat panel display terminal. This concept is very similar to the raster display system concept. The difference being that it can be used in conjunction with a slide or microfiche projector to project slides of a fixed map area on the back of the viewing screen with computer generated symbology superimposed on the map area. The utilization of an X-Y recorder has several advantages and disadvantages. The advantages are:

a. Several types available and easily adapted for the purpose.

b. Completed charts from the recorder could be used directly for debriefing purposes.

The major disadvantages, which far outweight the advantages, are:

a. It is a mechanical device, with slow response time and would be unduly stressed to cope with multiple moving target situations.

b. No capacity to present current moving target symbology without cluttering the map face.

c. Need to change chart for each exercise.

The slide system would be somewhat more flexible in that the user is only required to old maps and track histories with a cloth and cleaning fluid. While those systems have been used extensively in the past for training and experimental devices, they have been superseded by all-electronic systems that are more reliable, more flexible, require less floor space and are of lower cost.

The next approach to be explored is a random-scan graphic display system. This type of display system is in overwhelming favor over all of the types used for vehicle position charts. These systems usually are driven by a display processor which takes computer generated information and draws the required image.

Display generators can drive up to four separate display tubes. Stroke writing systems work basically in the same way as a X-Y recorder. The computer directs the position of the electron beam to any random location on the CRT surface and shapes any symbol, curve, or line that has to be drawn. This system has a high initial cost for the basic hardware which includes an interface unit for use with the digital computer, display generation equipment, and of course at least one display unit. Expansion to two or three additional display units requires nominal additional costs. The advantage of this system is that all information generated by computer programs can be changed quickly and easily. Symbology representing cultural targets, topographical features, own tank current position, pertinent data legends for annotating parameters such as speed and direction of tanks, targets, etc., are all generated by computer programs. Changing to a new tactical situation or selecting a new exercise, requires only a re-initiation of a previously stored computer program. The cost of graphic display systems is not as high as one might expect. Generally, basic systems that can provide the capability to depict FCIS own tank position, several targets, and fixed geographical and cultural references could be procured for less than $20,000 (without refresh memory). Although software must be generated (the driving mechanism), it is reusable and therefore can be amortized over many systems. A further significant advantage to this type of a vehicle position chart lies in the fact that it can be used for other purposes such as experimenter display and control functions for monitoring the results of experiments. This will be explored further in subsequent sections.

Another type of display system commonly used as a vehicle position chart is a raster type display system that employs commercial TV technology. The basic components are again, an interface unit for use with the simulation computer, a display generator, internal refresh memory, plus display equipment. These systems operate in a similar manner to the stroke writing systems mentioned previously, but do have some technical differences. The stroke writing systems typically can print an image of approximately 1,000 by 1,000 (horizontal and vertical) addressable elements in the display, whereas the raster scan type system can only address approximately 500 elements per horizontal line and, because of the need for synchronization time, only 480 lines per vertical frame. This apparent resolution limitation can be a significant factor in high data density displays.

A new and interesting multiplexed display technology that is now available and could be employed for the VPC is the plasma type display. This display is constructed of two laminated glass plates with each inside surface etched with conductive material. On one plate lines are etched in a horizontal direction; on the other in a vertical direction. The lines intersect at approximately 256,000 points on the surface of the screen in a pattern of 512 by 512. The space in between the two glass plates is filled with neon gas. The plates are electrically excited so that the neon gas at the intersections becomes ionized in a sequential manner, and may be modulated to produce displays that use all of the 512 accurately registered elements in both horizontal and vertical planes. A display generator operating in much the same way as the raster system display generator provides the image modulation information. The images can be either lines, circles, symbols or characters. This technology is available in another configuration utilizing a slide projector to project a map; e.g., a real-world tactical map on the back surface of the viewing glass while the computer generates the symbology for moving targets and FCIS, as well as track and other relevant information. The result of this is a system very similar to a raster display system but substantially lower in cost. Plasma displays are not as fast as raster displays in that each intersection has to be energized or de-energized separately, since only one X-Y address can be energized at any one time.

At this time, it would not be advisable to attempt to do a top level trade-off analysis in order to accept or reject any of these approaches. The reason for this is that several of the devices mentioned above have a flexibility which will allow them to be used not only as a vehicle position chart but as a display and control device for experimenters and/or instructors in the FCIS system. As a result, the trade-off analysis will be done after further discussion.

11.1.3.3 Instructor/Experimenter Display/Control Tradeoff Analysis. Any synthesized operational system, such as the FCIS-LM device must provide capabilities for instructors to conduct and observe training, for experimenters to develop experimental situations and monitor those situations, as well as analyze the results. Control stations have differing requirements and it is necessary to consider those requirements in terms of the various elements. First, the operator (either the instructor or experimenter) must be able to set up a problem prior to execution, monitor the state of the problem in real time, retrieve significant data concerning the problem in various formats, modify the problem if required, and receive and store results about the entire problem. In a simulator such as the FCIS, where all of the functional aspects of the training exercise are computed in realtime via a digital computer and reside instantaneously in core memory; i.e., a data pool, the instructor/experimenter display and control problem is reduced to the simple requirement of accessing information within the data pool and either displaying it, modifying it as required, or transforming it. Any analysis to develop display control requirements necessary for an experimenter or operator of this nature necessitates some investigation into the specific problem areas in order to develop a set of requirements. One of the early requirements identified was that of a vehicle position chart.

Next, it is necessary to consider all of the parameters and functions where the instructor/experimenter must have direct control. For example: the operator should be able to position the simulated own tank to any point in any gaming area. Targets in the environment must be initialized to their starting positions, the outside environmental conditions must be established and be controllable; and in the case where the instructor is acting as the driver, he must have vehicle dynamics information available as well as a means for controlling and changing those dynamics.

A further consideration involved in developing the layout of the control station is in how much information must be made available to the instructor, and what kind of, and how many displays are required. The FCIS-LM will be basically operated in two modes: a training mode and an experimental mode. The training mode should be the simplest mode with the instructor operating in this mode having a vehicle position chart as well as vehicle control display capability. This situation can be handled with one display if that display can provide both the VPC requirements as well as the vehicle control display requirements. There is, of course, the possibility that the instructor would lose continuity with the problem by changing displays in order to multiplex the different types of information on one display tube. Thus, although it is possible to use one display, it is desirable to use two.

A further consideration to be taken into account in this decision concerns the cost of the second display. Moreover, in the experimental mode, the control/display function takes on greater magnitude because not only will we have an instructor operating the simulator from the training aspect, but we will also need to have additional facilities for the 'experimenter' to perform his experimental functions. So at the very minimum, we need control/display capability for the instructor and also for the experimenter. As a result, it is necessary to have two separate displays available at the FCIS instructor/experimenter station. The results of this brief analysis are summarized in Table 11-1.

The following design concepts can be used to implement this approach. In all cases, the use of the vehicle position chart will be incorporated where applicable in the display control requirement. The first concept would be to provide individual controls for specific experimenter/instructor/control requirements. This would require, for example, an X-Y recorder or slide projector for vehicle position chart. Readouts and/or meters related to the driving controls would be necessary as well as individual readouts of other important environmental and tactical factors. In all cases, a visual repeater is required. Since the instructor requires display data entry capabilities, individual switches and/or potentiometers will be necessary.

TABLE 11-1 DISPLAY/CONTROL REQUIREMENTS

	MODE			
	TRAINING		EXPERIMENTAL	
PARAMETER	INSTR	EXPERI-MENTER	INS	EXP
VPC	X	NR	X	
MONITOR TRAINING PROBLEM	X	NR	X	X
ENTER DATA	X	NR	X	X
PERFORM DATA ANALYSIS		NR		X

Extending the use of the display technology introduced in the previous section, another solution to the problem is to use two graphic displays and one visual repeater. In this situation, the graphic displays would provide a vehicle position chart, alphanumeric readouts and control, and the driver controls. The vehicle position chart, would be implemented as described earlier. In addition, several different types of alphanumeric display control pages would be generated. These pages would be selectable either from a matrix of page select switches or could be selected from a tabulated index on a special CRT page. Pages would be grouped by type and category such as, malfunctions, target types, FCIS (own tank) data, weapon data readouts, environmental conditions, scoring criteria, etc. One of the special function pages would be the driver control page, where, if operating in the COFT mode, the instructor would have a page available with key entries to drive the simulator. Hardware for systems of this type are manufactured by companies such as Sanders, Aydin Controls, Vector-General, Inc., Imlac, Information Display, Inc., etc. A display system interfacing through a high-speed parallel interface would be necessary with display controller, internal refresh memory, and two display tubes. A system such as this would cost approximately $40,000 (initial procurement cost). Display tubes would be 19-inch diagonals with a usable display area of 12-inches x 16-inches. Displays would be tailored to instructor/experimenter requirements, with each page divided into sub-pages: a 12-inch x 12-inch area to display map information and alphanumeric data, and a supplementary area of 4-inches x 12-inches to be used for keyboard entry readout, and other scratch pad type data the instructors and/or experimenters may require.

Raster display systems will satisfy the alphanumeric display control functions discussed earlier, and at the same time, they could be used as vehicle position charts as well. To accomplish this, several techniques are available.

The most common method is to combine computer generated symbology with video tape signals prepared by scanning photo transparencies of selected maps.

Alphanumeric pages would operate in the same way as they do for the graphic system with the exception of sizing and format. A typical raster display system with a 19-inch diagonal tube would have a usable display area of about 12-inches x 15-inches. Systems of this type are manufactured by Aydin Controls, Ramtek, Inc. and Genisco Computer Products. The systems manufactured by Aydin have the capability to drive up to four display channels. They have the further capability to display images in color.

The plasma display mentioned earlier can be used as a vehicle position chart, as well as a display control device for the experimenter/operator. Products are available from several vendors which will allow the incorporation of either a microfiche or 35mm slide system to project background maps on the glass display surface and then superimpose the computer generated symbols for own tank, targets and related ground tracks. Display control capability would be handled in exactly the same manner as the two display systems previously mentioned. At the present time this system is off-the-shelf and can be readily purchased, although future procurements may be questionable since the U. S. company (Owens Illinois Company) having the technology to produce the glass plate element s has decided to terminate production. Whilst other sources are available in Japan, this aspect definitely discredits this approach for the FCIS-LM at this time. On the other hand, CRT tube production (both black and white, and color) is a well established technology employed in mass production and available from numerous U.S. sources.

A top level tradeoff eliminated the graphic display systems from further consideration based on its higher procurement cost, complexity and life cycle costs. Therefore, the selection of an approach to display and control will be based on a tradeoff between raster and plasma displays.

11.1.4 <u>Instructional Features</u>.

11.1.4.1 Problem Formulation and Control. The FCIS problem situation requires the instructor, operator and/or experimenter to establish the problem situation, and control that problem in real time. The elements of the problem that are controllable include the FCIS own tank and its related systems, the number of enemy targets, and a number of friendly forces. To understand the problem of control, consider the situation related to three enemy targets. If these are tanks, each of them must have speed and direction and behave in a proper manner. The instructor, if he is to control these, and if any degree of tactical realism is to be preserved, must have access to a pre-formulated battle plan for these vehicles in order to control the situation. It will not be possible for the instructor to control this situation effectively at the same time that he is required to instruct, observe, monitor and evaluate the FCIS own tank crew members. This identifies the need for an automated control system for problem situations. The digital computers, through program control, can independently control as many elements of the problem as computer capacity allows.

Problem formulation consists of the following tasks:

a) Initial problem setup.

b) Control of system malfunctions.

c) Control of the tactical scenario with up to 15 individual elements.

d) Control of environmental conditions.

e) If necessary, control of the FCIS own tank as a simulated driver.

f) Control of individual parameters to alter problem difficulty.

g) Determination of targets to be engaged or target engagement sequence.

h) Monitor all weapon systems, vehicle control systems, and sighting systems control status.

i) Monitor individual crew members' actions and reactions (including normal/emergency procedures) and a variety of crew interactive functions in response to a variety of terrain and threat stimuli.

When the trainer is used in a experimental mode, the experimenter must be able to perform many of the duties of the instructor, in addition to having to access the information required to perform an analysis on-line; e.g., determining the reaction time errors to certain stimulus.

All of these requirements can be segregated into two major categories:

1) Those tasks which are quantifiable in nature and consume time thus diverting attention from students.

2) The instructional tasks or experimenter tasks necessary and relevant to the problem at hand.

An automated problem control system can accommodate the first category and relieve the instructor/experimenter from these time-consuming tasks allowing him to devote more time to the second set of tasks. There are basically two ways to implement this type of a system. The first is to prepare, in detail, a "canned" set of problems where each specific element in the system performs exactly as defined with no deviations. These would then be a series of problems stored on a disk file and selectable one at a time for execution.

The second method is to utilize the computational capacity of the trainer computer system to develop a series of "computer programs," that would control various aspects of the tactical problems. This approach would take advantage of higher order languages and eliminate the inflexibility of a canned mission.

A programmed mission can be designed to adaptively respond to situations in real time. For an example, consider the insertion of a malfunction. In the first approach after the training exercise has progressed to a specific point in the mission a weapon system malfunction would be inserted. Assume it occurs a finite time after initial line-of-sight acquisition of a threat. This would be a good way to evaluate crew response to the malfunction if the tank commander and his crew followed up the situation; e.g., acquire the target and proceed to fire the weapon. The malfunction would be totally out of context and invaluable for performance evaluation of the desired response if the crew took alternate action such as seeking cover, or evading the threat. The method also has the capability to allow more variables to be introduced into the problem; e.g., this malfunction would not be inserted until the crew took appropriate action related to this particular problem element such as aligning the main gun and loading with appropriate rounds.

The basic difference between the two methods is not in their ultimate capability to handle a specific problem, but their overall flexibility as both these systems rely on computer program capability to implement control requirements. However, the method favored is that which is generated in the higher order language in a free format. This system introduces a flexibility not found in the "canned" approach. Each element of the problem can be categorized as a subroutine within Fortran in order to add flexibility to this system. A further example of the flexibility that could be incorporated; consider a target acquisition exercise within the favored formulation system. The target could be programmed to change speed or direction based on reactions of the FCIS own tank crew. Whereas in the "canned" method, once the target is initialized, the outcome would also tend to be "canned", and the tactical realism of the exercise would not be realized. Both methods, of course, have significant advantages over manual control. For instance, if there were three moving targets in the scene, with the instructor having to control all of the parameters related to those targets with individual controls, it is obvious that virtually no time will be available for crew observation and very little tactical realism will be achieved. Thus, the advantages of automated problem control becomes readily apparent.

The recommended design approach for this system would be one that operates with real-time overlays. Each problem would be defined off-line in a higher order language (HOL), such as Fortran. Individual problem elements such as initial conditions and environmental factors, target parameters, malfunctions, etc., would be developed separately and stored on separate disk files. An entire problem would be constructed by selecting individual elements from these files. The system also would have the capability to perform real-time data analysis as related to experimenter tasks. Systems of this nature have been incorporated in previous research tool type simulators (ASUPT and VTFS). The effort to develop viable problems is performed at a desk and off-line at the IO console. Once the task is completed, the user (either the instructor or experimenter) would simply select the appropriate function through the display control system.

11.1.4.2 Record/Playback. The training value of confronting a crew or crew member with a replay of a portion of a training exercise is well accepted and a record/playback capability should be incorporated in the FCIS-LM. The following summaries define approaches to record/playback previously implemented on various aircraft simulators.

a) Record Inputs - In this approach a history of the crew's inputs to the simulator are recorded in digital form. The playback is produced by functionally disabling the control inputs from the cockpit and replacing them in the computer with the recorded inputs. The normal computational functions of the computer are exercised as if the crew were operating the simulator. The system requires programs to handle the I/O and disable the controls during playback. This necessitates running the playback program during spare computer time. Some form of bulk storage device is required. Additional hardware is required to control the system.

b) Record Inputs and Selected Internal Variables - This approach is the same as a) except that certain equation outputs are recorded, and during playback, the computed values of the equations are replaced by the recorded values at a rate that prevents errors from propagating. This technique permits a reduction in the input rate to the computer from the recording medium.

c) Record Inputs and All Outputs - In this approach all outputs and inputs to the simulator are recorded. During playback, values of the recorded inputs are used to drive the flight controls, while outputs are used to drive displays. The computational function of the computer is bypassed. Programs are required to handle the I/O and perform the executive function. Hardware requirements are the same as for the previous approaches.

d) Record Outputs - A further approach is to record only the outputs of the vehicle systems in response to control inputs. During playback, crew inputs are disabled and computation is stopped. The system simply provides the outputs as recorded. Executive and I/O programs are required along with hardware similar to that for the previous approaches. The controls are not moved during this approach.

Link's experience indicates that approach b) 'Record Inputs and Selected Internal Variables', yields the most satisfactory playback and recommends this approach for the FCIS-LM.

The FCIS application of the SOW requirement for the most recent thirty minutes does not provide the most effective training. Tank engagements are of short duration. To achieve maximum value of the recorded performance the record/playback capability should allow the instructor to record and then playback selected segments of simulator performance. A total of 30 one-minute segments of recording time should be available. The instructor should have record/playback control via display and control function keys. He must be able to initiate a recording, select segments for playback, freeze and unfreeze a playback, and erase or overwrite a recorded segment. The instructor must also be able to select normal or half-time playback. Playback does not destroy the recorded data. When playback of a segment is complete, the system retains the conditions existing at the end of the playback segment.

Record/playback records are generated by on-line real-time software. For every one-minute segment, a large initialization record is stored on the disk. Each initialization record contains sufficient data to reset the state of all simulated systems to this point in time. During the one-minute interval, the record program collects and buffers inputs to the computer from the vehicle controls and specific variables resulting from simulation computations. Values are recorded at a rate corresponding to the generation or utilization of the data by the simulation routines. These smaller reproduction records are sized so that data can be efficiently transferred to the disk. When recording is terminated, the file content record (on disk) is updated with pointer and control information to be used for display of segments used and for replay control.

Replay is accomplished by an on-line real-time routine which utilizes the initialization data to return each simulated system to the state existing at the time the initialization data was recorded. Upon completion of the initialization process, the simulator will be in the freeze mode (functions of time will be halted). Also, all inputs to the computer, corresponding to those which were recorded, are discontinued for the duration of the replay. When freeze is released bv the instructor. reproduction data records are retrieved from the disk and the input and internal variable values distributed in a manner that is essentially the inverse of the collection process.

In flight simulators, the primary flight controls and rudder pedals are driven during playback to simulate the control movements that occurred during the recording period. Secondary controls such as throttles, flap handle, and switches, etc., are not moved during the playback, but the effects of their movement are visible on cockpit instrumentation. Due to the largely analog nature of the tank systems, further study is required to determine the most effective systems operation during playback.

Two approaches to instructor station displays during record/playback have been utilized in the past. One approach involves recording the selection of the display pages and recalling them during playback. The other does not record display selections so that during playback the instructor is free to choose the display most pertinent to the situation. In both approaches, changes to the simulation problem entered via the display/control system, are recorded and replayed at the appropriate time. In order to provide maximum flexibility to the instructor, the second approach is recommended for FCIS-LM instructor station displays.

11.1.4.3 Performance Monitoring. The performance monitoring capability required by the FCIS must incorporate not only individual crew task assessment and full crew interactive assessment, but must also provide the experimenter with the capability to assess results of the various experiments that will be performed with this laboratory model. As a result, an evaluation of only the crew tasks would not be sufficient to develop requirements for a performance monitoring system. Considerable attention must be paid to the needs of the experimenter on this synthetic system. Thus, any performance monitoring systems incorporated must include not only performance monitoring capabilities for specific tactical training situations, but must also address the experimental situation.

Table 11-2 summarizes several engagements for the M60A3 operational tank typifying problems that would be presented to crews in the FCIS. This serves as a data base from which to establish the performance monitoring requirements related to instructing and accordingly provides the basis for determining the types of performance monitoring capabilities that are required at the instructor/experimenter control station. Review of this data indicates that during engagements, several control activations are made, such as, indexing ammunition into ballistics computer, selecting firing switches, loading rounds, etc. This identifies the need to

TABLE 11-2 SCENARIO INDEX FOR M60A3 TANK, BASED UPON TABLE VIII A AND B (TWENTY ENGAGEMENTS) STABILIZED MODE

ENGAGE-MENT	TANK MODE	TARGET DESCRIPTION	TYPE ENGAGEMENT	RANGE	ILLUMI-NATION	OTHER
1	MOVING TANK	TANK FRONT SHOT	BATTLESIGHT HEAT	900 METERS	DAY	
2	MOVING TANK	MOVING TRUCK	CAL 50	700 METERS	DAY	
3a	MOVING TANK	MOVING TANK	BATTLESIGHT	1200 METERS	DAY	MULTIPLE
3b	MOVING TANK	MOVING TANK	APDS	1600 METERS	DAY	ENGAGE-MENT
4	MOVING TANK	TROOPS	COAX	600 METERS	DAY	
5	STATIONARY TANK	ANTITANK	PRECISION TELESCOPE HEP	1600 METERS	DAY	
6	MOVING TANK	HELICOPTER	CAL 50	900 METERS	NIGHT	
7	STATIONARY TANK	TANK FRONT SHOT	BATTLESIGHT HEAT	1000 METERS	NIGHT	THERMAL SIGHT
8	STATIONARY TANK	TROOPS	CAL 50	1200 METERS	NIGHT	THERMAL SIGHT
9	STATIONARY TANK	TANK FRONT SHOT	PRECISION ADPS	1800 METERS	NIGHT	THERMAL SIGHT
10	MOVING TANK	SUSPECTED TARGET	SUPPRESSIVE FIRES LOADERS MG	100 METERS	NIGHT	
11	MOVING TANK	HELICOPTER ATGM	CAL 50	1000 METERS	DAY	EVASIVE MOVES
12	STATIONARY TANK	TANK FRONT SHOT	PRECISION ADPS	1900 METERS	DAY	SIMUL-TANEOUS WITH ENGAGE-MENT 13

TABLE 11-2 SCENARIO INDEX FOR M60A3 TANK, BASED UPON TABLE VIII A AND B (TWENTY ENGAGEMENTS) STABILIZED MODE (CONT'D)

ENGAGE-MENT	TANK MODE	TARGET DESCRIPTION	TYPE ENGAGEMENT	RANGE	ILLUMI-NATION	OTHER
13	STATIONARY TANK	TROOPS	CAL 50	1500 METERS	DAY	SIMUL-TANEOUS WITH ENGAGE-MENT 12
14	MOVING TANK	TANK FRONT SHOT	BATTLESIGHT HEAT	800 METERS	DAY	
15	MOVING TANK	SUSPECTED TARGET	SUPPRESSIVE FIRES COAX	500 METERS	DAY	
16	MOVING TANK	TANK FRONT SHOT	BATTLESIGHT HEAT	800 METERS	NIGHT	THERMAL SIGHT
17	MOVING TANK	MOVING TRUCK	COAX	700 METERS	NIGHT	THERMAL SIGHT
18a	MOVING TANK	TANK FRONT SHOT	BATTLESIGHT	1300 METERS	NIGHT	MULTIPLE
18b	MOVING TANK	TANK FLANK SHOT	ADPS	1500 METERS	THERMAL SIGHT	ENGAGE-MENT
19	MOVING TANK	TROOPS	COAX	600 METERS	NIGHT	THERMAL SIGHT
20	STATIONARY TANK	ANTITANK	PRECISION TELESCOPE HEP	1500 METERS	NIGHT FLARE	

be able to monitor various switches, controls, and simulated turret and cupola positions. In addition, a substantial amount of performance of task activity is through voice controls. This latter capability implies the need for either a manual or automatic mechanism by which the computer can understand voice commands given by the commander and responses provided by the remainder of the crew. One method for implementation would be to provide the system operator with a voice command consent switch and by monitoring the crew conversations and hearing the correct commands could key in either a code or a number related to a list on a CRT page or a placard indicating which message was transmitted. An alternative would be to provide an automated voice recognition system which would have a limited vocabulary but one which would be sufficient for the types of commands given in these scenarios. Then the computer would make decisions based on the inputs received through this system. There is, however, a simple method which may prove to be totally adequate for a performance monitoring type system; one which does not analyze individual crew responses in determining correct actions but observes the overall problem.

Each engagement in a total problem can be considered somewhat like a procedure in which some general activities such as maneuvering, acquiring line-of-sight, and recognition of a target may occur. A further sequence involves aligning and loading the proper weapon, firing and observing the first round, and completing the engagement by firing the second round. Since it appears that the overall requirements of the tank crew are to acquire targets as soon as possible and fire the first round within a period of seconds, and then fire the second round in another period of time, a performance monitoring system which could provide displays of these key activities would provide observers with information on overall performance. Alternatives to this approach would include monitoring all activities in the vehicle (switches and controls) and printing out event times on-line in real time as the actions occur and then scoring weapons firing. Systems like this have been implemented in previous simulators. The overall result of these was to provide confusing data and extensive hardcopy printout that was seldom used. The philosophy that must be employed is to use the capacity of the digital computer available to assist the instructors in performing performance monitoring tasks.

One other major aspect that must be considered is the needs of the experimenter. In order to perform experiments in training research, it is necessary, not only to have all the facilities available to the FCIS instructor, but to also have the same capabilities available to a general training researcher. In this light, one can think of the instructor's performance monitoring requirements as a sub-set of the experimenter's performance monitoring requirements. Thus, the researcher's requirements impose more severe performance requirements on this system. As a research tool, the FCIS must be capable of exploring such issues as the need for and extent of kinesthetic cues, variability of visual cues, and information feedback requirements for students, use of various instructional strategies in teaching tasks related to FCIS operations, etc. Assuming that the experimenter will have all the instructor's capabilities, the issues to be addressed here would include those above and beyond the training performance monitoring requirement. The FCIS real-time simulation programs will generate a vast amount of data that can be handled in one of two ways. Data could be stored away on some mass storage medium for later processing, analyzing and evaluation, or it can be analyzed by the computer in real time and displayed to the researcher. It is essential that both of these capabilities be provided, and because of the advanced capabilities of current computer technology and software languages, providing these capabilities does not require a substantial cost increase. The simplest means of storing large amounts of data for later output or processing would be to use the capabilities of random access, mass storage disk file, or a magnetic tape unit. Data would be stored on a time base with the experimenter defining system characteristics such as the amount of data to be stored, data sampling rate, and length of time the data should be stored. Being stored in accessible files on either disk or tape, batch programs could be used to process data to provide line printer output or curves in processed form. A more stringent application would be the real-time processing of data to provide instantaneous analysis of problem development. The problem formulation system data transformation algorithms can be generated and stored as relocatable Fortran modules to be activated as overlays in real time. Measures such as RMS values, maximum values, average values, etc., could be programmed in Fortran and stored in this manner. Upon activation, these programs would monitor any simulator variables assigned and provide the results as CRT displays or possibly as plots. The instructor and the experimenter must be provided with overall performance monitoring capabilities. The instructor requirements include observation of individual and interactive crew tasks. The concept using a simulated procedures monitoring system as mentioned earlier appears to provide a succinct assessment of performance that would be relevant for the type of training on going in FCIS. For the experimenter, the system must be expanded to include real-time storage of large amounts of data and on-line analysis of that data for display to the instructor.

11.1.4.4 Briefing/Debriefing. Since the recommended approach for trainee briefing involves personal contact between instructor and trainees, no instructional development or additional study effort is required.

The instructor requires permanent recordings of performance results in a form suitable for debriefing and record-keeping. The capability to hardcopy instructor displays has, in the past, provided an efficient and cost-effecitve approach to debriefing requirements. The type of display (raster or plasma) to be selected for the instructor station, mav affect the implementation method selected for hardcopy although the instructor control of hardcopy will be independent of the final approach. In many Link simulators, hardcopy printout of any instructional system display may be obtained by identifying the display (function switch for each display) and activating the hardcopy function switch.

If a raster display system is utilized, an image of the display page code will be transferred to a hardcopy buffer area in the computer memory for output to the hardcopy device. A control program is used to queue requests and provide the necessary interface signals required so that output to the hardcopy device proceeds in an efficient manner. Hardcopy units for raster displays are commercially available. Link has used Tektronix copiers with Aydin Controls' CRT displays on several flight simulators and is familiar with the interfacing requirements to provide remote control of the hardcopy unit from the instructor station.

A hardcopy unit for a plasma panel display will soon be commercially available. Current information indicates that it would operate in a manner similar to the hardcopy unit with a raster display.

11.1.4.5 Demonstrations. Demonstration teaching is one of the oldest techniques used in training. Demonstrations are used to familiarize the student with a sequence of events, peculiar problems, and performance standards associated with tasks. They are especially valuable where the object of learning involves operation of a complex system in a hostile environment. Demonstrations can be a convenient way of illustrating the interdependencies between the weapons systems and the technical environment, and in defining the tactical decision making process involved in a particular situation.

The trainer record/playback capability, particularly the software programs, can with minor extensions, be used to provide demonstration capability. A demonstration is simply a permanent record/playback. Once generated, they would be stored on disk and selected and activated by the instructor via the display/control system keyboard. It would be possible to create tape libraries of demonstrations if the number of demos exceeds the allocated disk space.

Automated demonstrations provide a standardized method of instruction and elevate the instructor role to that of observer, affording him more time to advise and comment on the different technical situations presented to the crew members. Demonstration capability would enhance training effectiveness of the FCIS-LM device with an insignificant impact on cost; and therefore it should be included. Based on the relatively short engagements in tank warfare, a maximum length of two minutes per demonstration, and a total of twenty demonstrations should provide an adequate variety of engagements. Due to their brevity, no internal reset points are required. Once initiated, the demonstration would run to completion, although it will be possible to "freeze" the demonstration at any point.

11.1.4.6 Scoring. Scoring algorithms provided must be applicable to typical problems such as those outlined in section 5.2.1 (Scenarios of Engagements). Algorithm scoring can also be incorporated by using the problem formulation system. For each type of engagement, a separate performance measurement/scoring algorithm could be provided and programmed in Fortran. Initiation of the engagement would also activate the performance measurement algorithm, which in turn would monitor the engagement activity, and provide results.

At this stage in the study program it is somewhat difficult to detail the elements of the algorithms. Many issues remain unsettled in terms of assessment of tank crew performance; e.g., does one address only the performance of the crew in its entirety or each individual member, providing scores for each crew member or for the entire crew. Also, is the tank commander, being ultimately responsible for that behavior of the tank and crew scored without regard to the actions of others. The capabilities provided by a system of this kind are innumerable. As long as data is available in the computer, the overlayable engagement scoring algorithms can monitor procedural actions, time based performance and instantaneous measurements, such as miss distance. These separate scoring elements can then be combined into final scores for engagements. The system envisioned would also allow for on-line update and generation of the overlay algorithms and from this standpoint can be considered as a computer program. The result is that system capability and flexibility would be limited by only two things: a) the capability of the digital computer to perform certain computations and keep track of certain events, and b) the imagination of the user.

11.1.4.7 Record/Playback Audio. In the simulated M60A3 environment where many crew actions are based on voice commands and responses, a record/playback system with synchronized audio will provide valuable information to the instructor critiquing crew interaction. Link recognizes the value of record/playback audio and has provided both record/playback and demonstration audio on a variety of simulators and considers it an important requirement for the FCIS-LM device.

One approach for implementing the record/playback audio system requirement was an Emerson Electric four-track tape transport and electronic assembly supplied by Telemetry Systems Engineering. This system is referred to as the Quick Access Audio Cartridge System (QUAACS). Multitrack audio tape heads permit selective track recording or playback and single-track signal erasure while recording. The system allows the user to record and playback audio data at 15/16 inches per second. QUAACS permits the rapid search of a magnetic tape cartridge at 120 inches per second by a digital computer. This system can, under computer control, meet the access requirements for 30 one-minute playback segments and also provide continuous recording of up to 30 minutes of the training exercise audio.

Another record/playback audio approach involves use of multiple tape cartridge machines of the type manufactured by Broadcast Electronics (BE). A full range of record and playback units is available and Link has used a number of different models for various simulator applications. The FCIS application will require a cartridge machine with both record and playback capability from the BE Series 3000. Normal tape speed is 7.5 ips and the optional fast forward speed is 22.5 ips; remote control capability is available. To meet a 'ready-for-playback' requirement of 30 seconds or less the system would require a 15 unit configuration. The cost of this configuration is high and further analysis to determine if an alternate configuration of 10 units at half the cost and providing the same training capability but requiring a 40 second delay, is necessary.

A third approach to providing record/playback audio employs a very simple digital voice technique. During the record mode the crew voices are converted from analog into digital form and stored on the disk; in playback the digital data is converted back to analog. This approach storage limited only by the amount of disk space allocated. Access time for disk data is negligible. The audio reproduced by the digital technique may not have the same level of fidelity to human speech as the previously described tape systems provide. Although a digital voice system is not commercially available at this time, the approach is extremely attractive and Link is presently investigating commercially available components to configure such a system. Link is also conducting an in-house design effort in order to provide a digital voice system as part of a current contract.

All three approaches described could be used to meet the FCIS record/playback audio requirement and will be considered in design tradeoff selections in the following sections of this report.

11.1.5 System Design Tradeoff and Selection. This section presents the detailed tradeoff analysis required to select an approach for the display system and the record/playback audio system. Performance parameters for each system were identified and assigned weighting factors. The evaluation factor (EF) represents the capability of the candidate approach to meet the performance parameter. A high EF number indicates better performance.

11.1.5.1 Display System. The display system for the FCIS will provide instructor control of the training problem as well as vehicle position chart display capability. As indicated in previous sections the candidate approaches have been narrowed to two for further evaluation; i.e., raster display and plasma display.

Five performance parameters were identified for the display system. Color was selected as a performance parameter since a color display provides greater information density, encoding capability and message categorization; e.g., green for instructor alerts. The hardcopy capability is a statement of work requirement. The EF was used in this case to indicate the availability of a hardcopy device for each approach as well as Link's experience with it. Display update speed is a measure of the system's capability to present new data for display. Indicator size reflects the availability of different size displays at the instructor's station. Computer impact provides an indication of the extent of the interface necessary between the display system and the main computer complex, both hardware and software. In this case, the lower the computer impact received, the higher the rating; so that the higher EF number always indicates superior performance. As a result of the evaluation shown in Table 11-3, the raster display has been selected for the instructor station display system. Although the scores were close, subjective opinion reinforces its selection. Although the plasma display represents a technologically simple approach and is very attractive from a reliability/maintainability (R & M) standpoint, the question of future plasma panel availability is serious enough to discount this approach.

11.1.5.2 Record/Playback. Three candidate approaches for record/playback audio were described in Section 11.1.4.7. Three performance parameters were defined. Access time represents the ability of a system to be ready for playback in the time allotted in the statement of work (30 seconds or less). Recording time is the amount of available time in the proposed system. The quality of voice represents the system's reproduction fidelity.

As a result of the analysis detailed in Table 11-4 the digital voice technique has been selected to implement the record/playback audio. Although the digital voice technique involves a development effort, its simplicity, high reliability, and resulting low life-cycle cost (LCC) will make a significant contribution to state-of-the-art training technology.

11.1.6 Instructor Station Configuration. The FCIS-LM device is configured with two separate crew training stations, one for the driver and one for the crew in the turret (the commander, gunner and loader).

11.1.6.1 Instructor Observation Stations. Instructor/Observer positions at both training stations have been located on the motion platform, behind the crew member(s) so that the actions of the crew, control and instrument status, and a proper perspective of the visual scene may be observed during training (figures 11-2 and 11-3). Due to cost considerations, the instructors will have no CRT and minimal controls on the motion platforms, but will effect control, monitoring and evaluation inputs via intercom to an instructor with full controls at the main instructor/experimenter station. At both instructor/observer stations

TABLE 11-3 TRADEOFF ANALYSIS CHART INSTRUCTOR DISPLAY FUNCTION

	TRADE-OFF PARAMETERS AND SELECTION CRITERIA	WEIGHTING FACTOR	RASTER DISPLAY		PLASMA DISPLAY							
			EF	FM	EF	FM	EF	FM	EF	FM	EF	FM
PARAMETERS	PERFORMANCE PARAMETERS											
	• COLOR DISPLAY	.3	5	1.5	2	.6						
	• HARDCOPY CAPABILITY	.6	4	2.4	1	.6						
	• DISPLAY UPDATE SPEED	.6	4	2.4	2	1.2						
	• INDICATOR SIZE	.2	5	1.0	2	.4						
	• COMPUTER IMPACT	.8	4	3.2	3	2.4						
	PERFORMANCE SUMMATION			10.5		5.2						
CRITERIA	OVERALL PERFORMANCE			2.1		1.0						
	LOW PROCUREMENT COST	.2	3	.6	4	.6						
	LOW OPERATING COST	.7	3	2.1	3	2.1						
	SIMPLICITY	.5	3	1.5	4	2.0						
	RELIABILITY	.5	3	1.5	4	2.0						
	MAINTAINABILITY	.5	2	1.0	4	2.0						
	SYSTEM COMPATABILITY	.5	3	1.5	3	1.5						
	SYSTEM FLEXIBILITY	.5	4	2.0	3	1.5						
	PRODUCIBILITY/AVAILABILITY	.6	5	3.0	2	1.2						
	SAFETY ASPECTS	.5	3	1.5	5	2.5						
	OVERALL SUMMATION		16.8		16.4							
	APPROACH REJECTION/SELECTION		✓		X							

TABLE 11-4 TRADEOFF ANALYSIS CHART RECORD/PLAYBACK AUDIO FUNCTION

	TRADE-OFF PARAMETERS AND SELECTION CRITERIA	WEIGHTING FACTOR	DIGITAL VOICE		QUAACS		BROADCAST ELECTRONICS					
PARAMETERS	PERFORMANCE PARAMETERS		EF	FM	EF	FM	EF	FM	EF	FM	EF	FM
	• ACCESS TIME	.8	5	4.0	4	3.2	0	.0				
	• RECORDING TIME	.2	4	.8	4	.8	3	.6				
	• QUALITY OF VOICE	.5	3	1.5	5	2.5	5	2.5				
	•											
	•											
	PERFORMANCE SUMMATION			6.3		6.5		3.1				
CRITERIA	OVERALL PERFORMANCE			2.1		2.2		1.0				
	LOW PROCUREMENT COST	.4	2	.8	2	.8	2	.8				
	LOW OPERATING COST	.7	5	3.5	3	2.1	3	2.1				
	SIMPLICITY	.5	5	2.5	4	2.0	4	2.0				
	RELIABILITY	.6	5	3.0	3	1.8	3	1.8				
	MAINTAINABILITY	.6	5	3.0	3	1.8	3	1.8				
	SYSTEM COMPATABILITY	.4	3	1.2	3	1.2	3	1.2				
	SYSTEM FLEXIBILITY	.4	4	1.6	4	1.6	3	1.2				
	PRODUCIBILITY/AVAILABILITY	.6	3	1.8	4	2.4	5	3.0				
	SAFETY ASPECTS	.3	5	1.5	4	1.2	4	1.2				
	OVERALL SUMMATION		21.0		17.1		16.1					
	APPROACH REJECTION/SELECTION		✓		✗		✗					

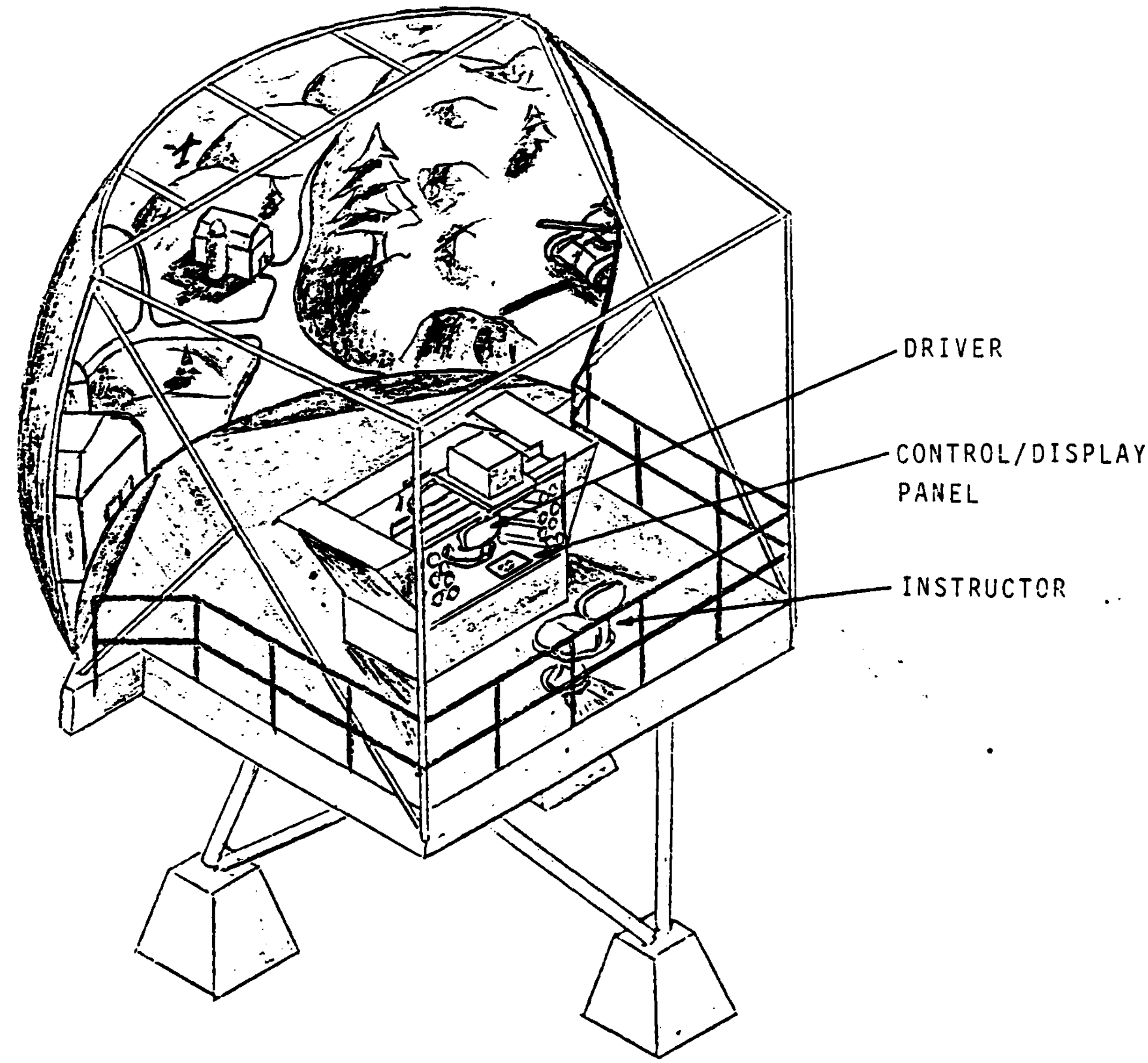

Figure 11-2 FCIS-LM Driver Station Instructor/Observer Position

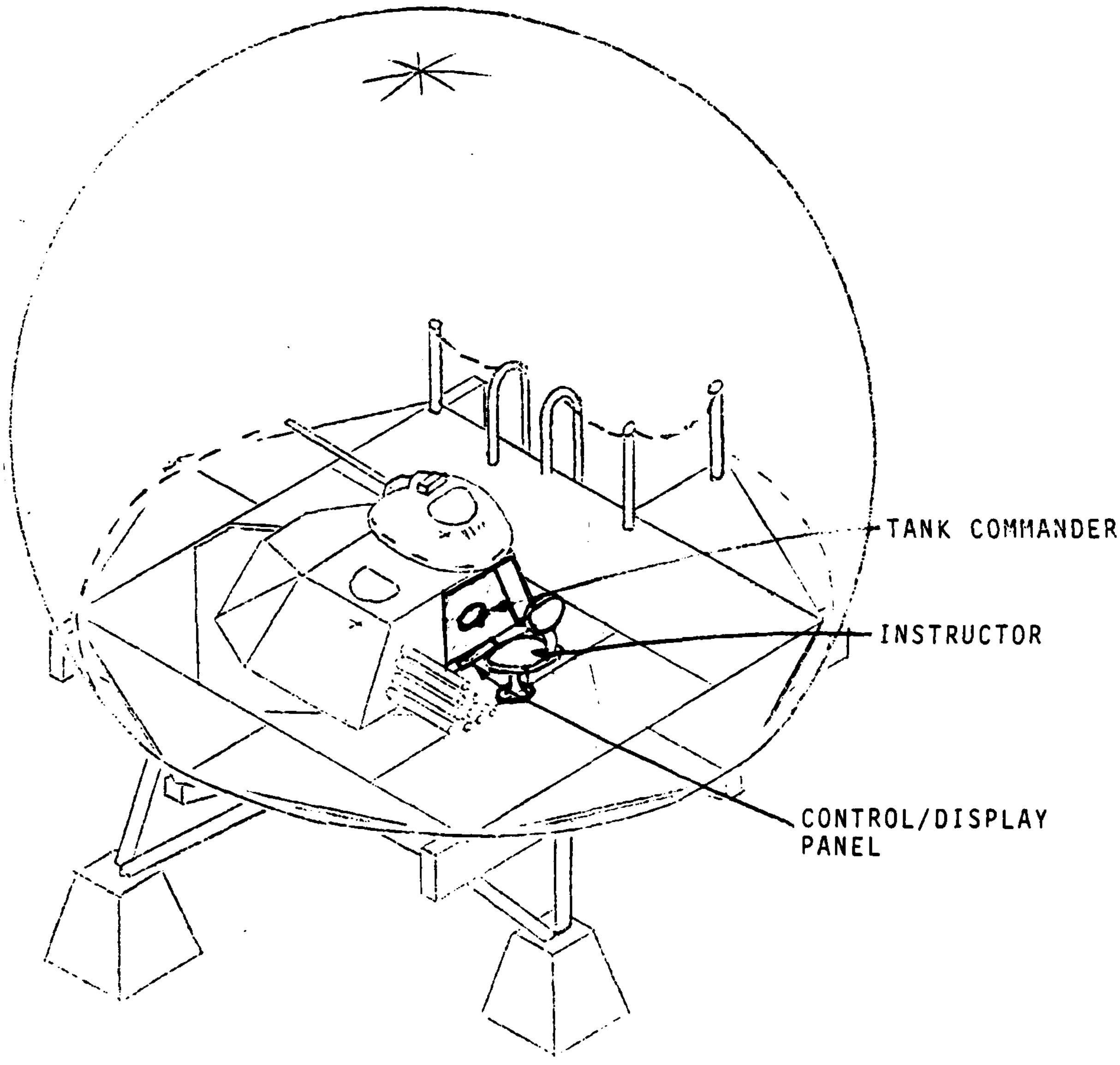

Figure 11-3 FCIS-LM Fighting Station Instructor/Observer Position

there will be controls to:

- o Cutoff power to the entire complex (emergency only);
- o Freeze or unfreeze the training problem;
- o Turn the motion system on or off;
- o Operate the instructor's intercom system.

The instructors will also have indicator lights showing the status of all safety interlocks associated with the motion system. All of these controls and indicators will be visible and within reach of the tank commander or driver (as appropriate), should training be conducted without an instructor present on the motion platform.

11.1.6.2 Main Instructor/Experimenter Station. The main instructor/experimenter station will be located in the computer room. A conventional instructor station layout and structure will be used, having four (4) CRT displays. (See figure 11-4). The leftmost display will be a visual system monitor for the gunner's or the commander's optical or I.R. systems. Below this display are the controls to select either gunner or commander visual sight functions. When "Gunner" is selected, whichever system the gunner is using will be displayed, with reticle when appropriate (the default will be his 1X periscope). When "Commander" is selected, the results will be the same, except the default will be his 8X system.

The second display will repeat any one of the four fighting station visual channels or any of the two driver station visual channels. The selection controls are located directly below this repeater.

The third display is the instructors primary alphanumeric/tactical map CRT. From this position, using the controls mounted below the CRT, the instructor is able to perform all of the necessary instructor functions, including problem initialization and control, selection and activation of the automated training features, calls for hardcopy printout and operate the intercom. In the 'MAP' mode, the instructor will be able to observe, as though from above, the entire battle area complete with significant terrain features and the position and movement of all friendly and threat forces.

The fourth display is for the instructor's use during complex operations. It will allow him to simultaneously display a map and a problem control format. This display is also used by an experimenter during research. Below this display are mounted controls for altering and adapting the various systems and capabilities during research and for controlling specialized monitoring, control, scoring, recording, and evaluating CRT formats.

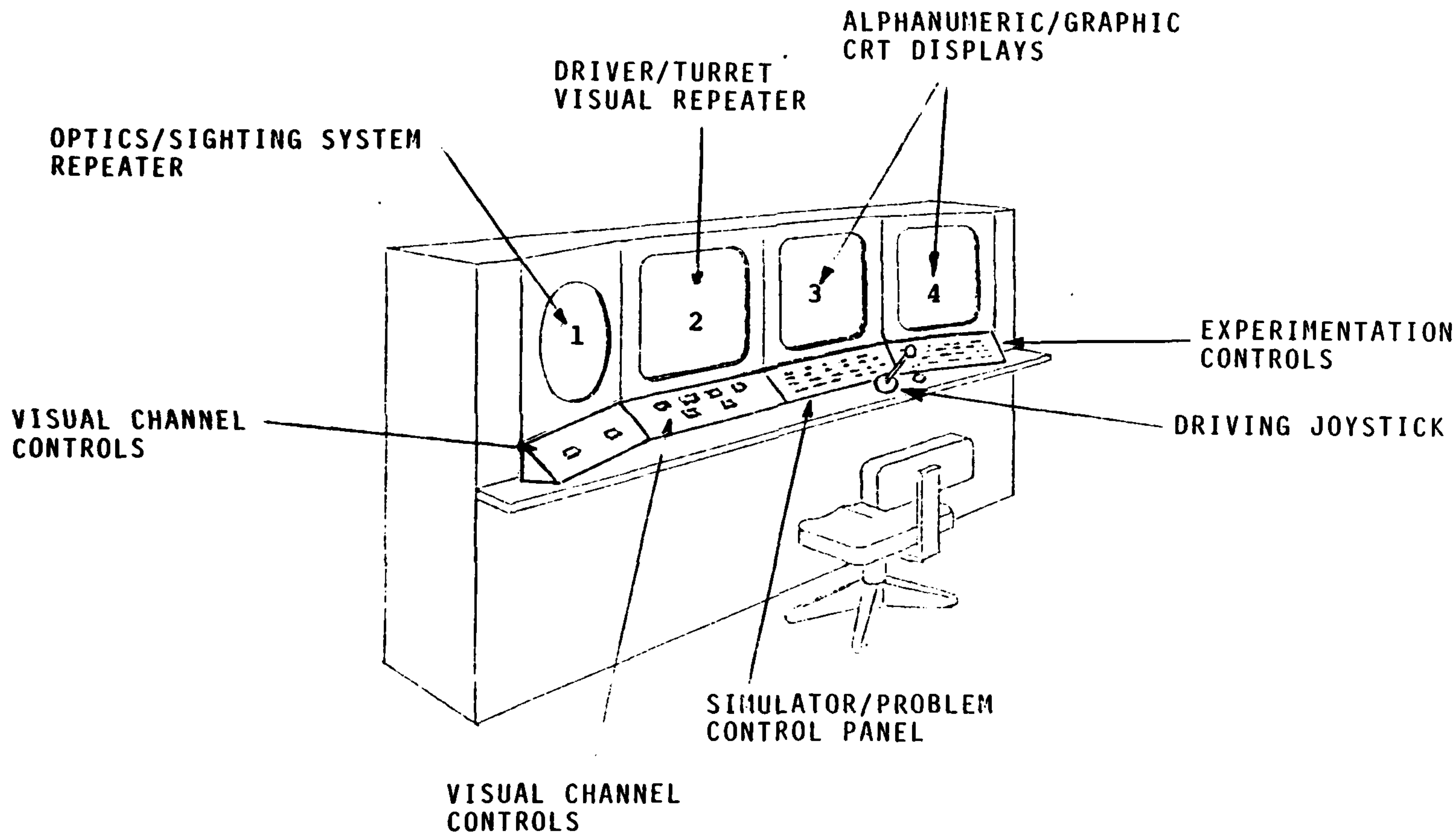

Figure 11-4 FCIS-LM Instructor/Experimenter Station

11.1.7 Instructional Features.

11.1.7.1 Instructor and Experimenter Control/Display Medium. Instructor/experimenter control and display functions can be implemented with the same type hardware as the Vehicle Position Chart) (VPC). This approach is based on the preliminary trade-offs which established the flat panel display and the raster scan CRT system, as the candidate systems for both requirements. Further analysis led to the selection of the raster CRT display. Two typical systems are shown in figures 11-5 and 11-6.

Either of the systems illustrated has the capability to display computer generated symbology in tabular or graphic form. In addition, through additional electronics, video images of gaming area maps may be mixed with the computer-generated video signals to form composite images. This display system would meet the FCIS-LM display and control requirements by operating in two modes. One mode, being MAP or the VPC, and the other, which is of more interest in this section, is the problem monitoring and control.

The recommended system utilizes alphanumeric page formats, where each page contains fixed text (descriptions, units, etc.) and variable data (current value of simulation variables). Pages are organized according to functions; e.g., system malfunctions, weapons delivery, etc. In essence, this system performs two functions. First, data in the simulation datapool is displayed to the user and, second, keyboard inputs modifying that data are inserted into the datapool. (It should be noted that these systems do have limited graphics capability, but displays can be formatted in that manner, if required.)

Since these functions are general in nature, a functional specification for a software package to drive these displays can also be formulated.

A page preparation program should be provided so that the operator has a means of generating or changing any CRT page provided with the FCIS simulator. The page should be generated on the actual CRT at the Instructor Station.

The CRT page may be made up of any combination of fixed words and phrases, and computer-supplied responses. The page format should make the following provisions:

a) Lines must be available for alerts and inputs.

b) Space must be allowed for ten digits of computer-supplied values.

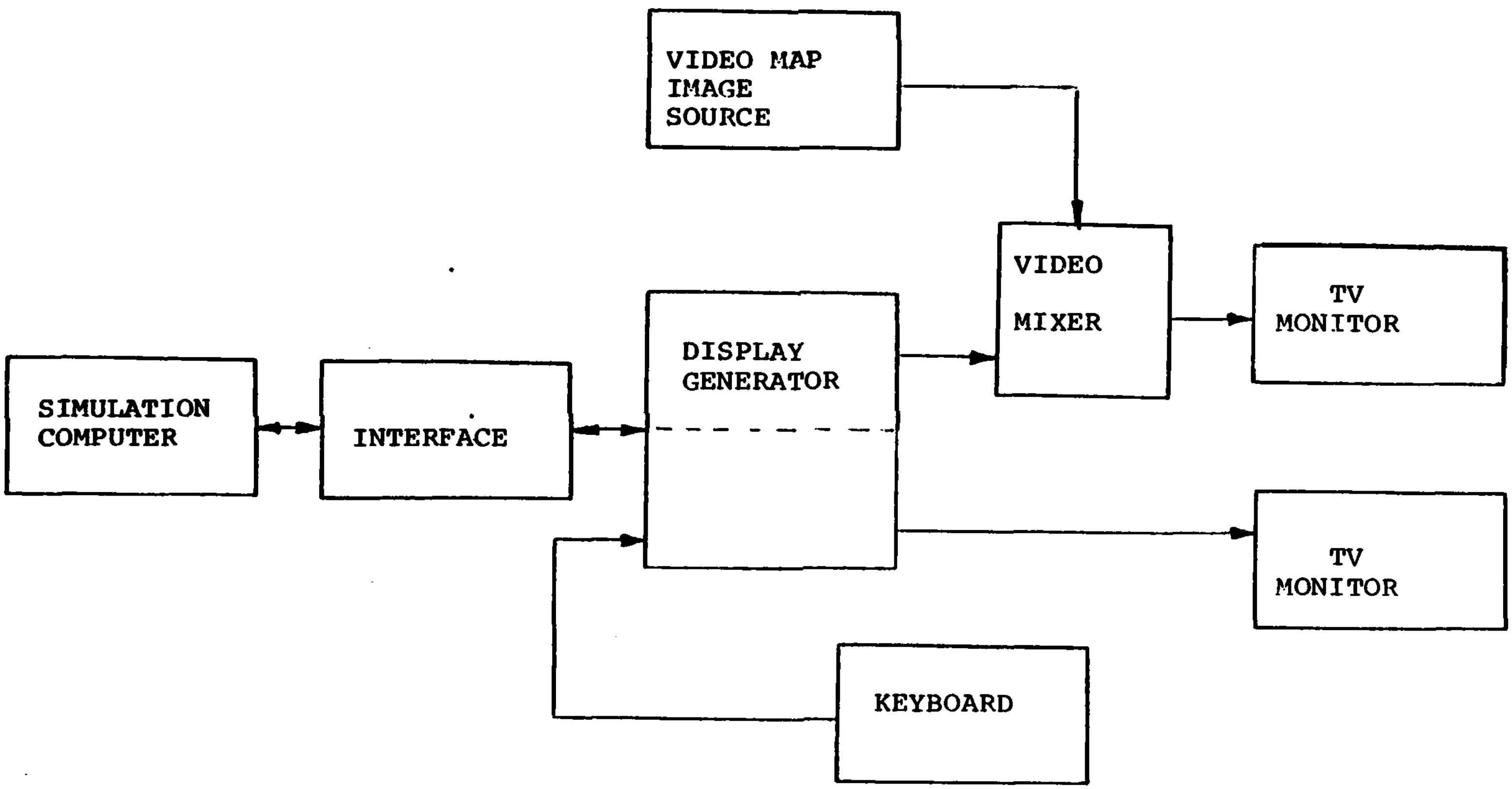

Figure 11-5 FCIS-LM Instructor/Experimenter Display System (Example 1)

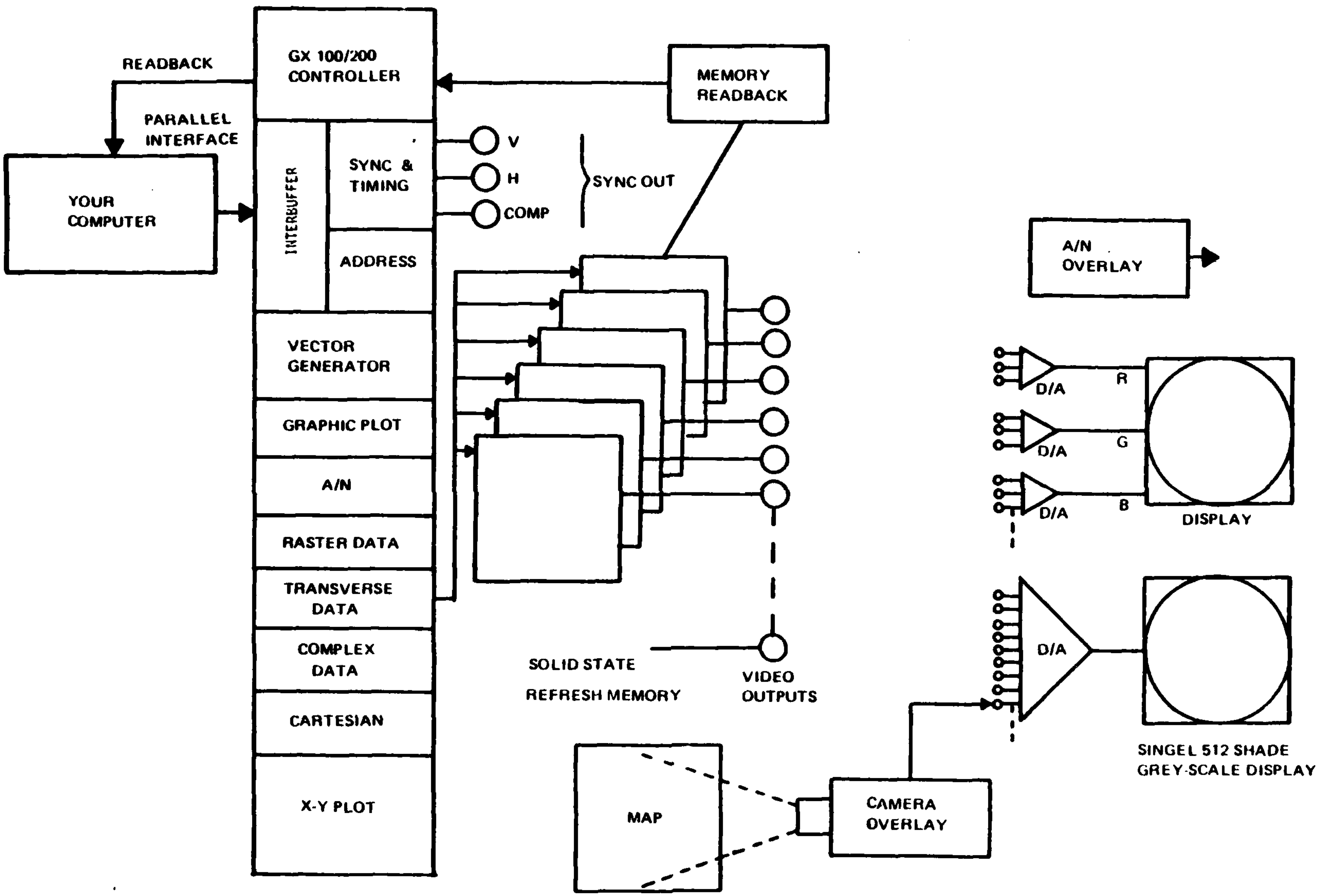

Figure 11-6 FCIS-LM Instructor/Experimenter Display System (Example 2)

c) No more than 80 computer responses can be placed on a CRT page.

Once a page has been selected for change or generation, the program will enter a generation mode. While in this mode, the instruction page will be displayed on one CRT (the second A/N CRT at the IOS which displays pages) and the page being changed or generated will be displayed on the other (the A/N CRT which displays keyboard entries at the IES). Keyboard control will automatically transfer to the appropriate CRT. Any keyboard entry from the IES, while in the generation mode, will be processed as an entry to this CRT and will be accepted as a CRT page change.

Figure 11-7 illustrates the generation mode format of a page, and figure 11-8 illustrates how the page displays the desired values.

When the manual page program has completed processing the information transmitted to it by XMIT P.PAGE, it will display the generated page with all computer response areas blank (the processing may take more than one minute). If an undefined program symbol has been detected, the word ERROR will appear instead of the blank area. ERROR will become a permanent word and remain on the page until the operator takes appropriate action to correct it.

<MTIME>	SECONDS	MISSION TIME
<ATIME>	SECONDS	TIME SINCE ENGAGEMENT START
<01ENGAGE>		INITIATE NEW ENGAGEMENT
<02TGTNO>		NEW TARGET
<AZIM>	DEGREES	TURRET AZIMUTH (FROM TGT)
<ELEV>	DEGREES	TURRET ELEVATION
<HDG>	DEGREES	TRUE HEADING

Figure 11-7 Typical CRT Page Generation Mode Format

	240.4	SECONDS	MISSION TIME
	1.8	SECONDS	TIME SINCE ENGAGEMENT START
01	FALSE		INITIATE ENGAGEMENT
02	04		NEW TGT
	74	DEGREES	TURRET AZIMUTH (FROM TGT)
	4	DEGREES	TURRET ELEVATION
	190	DEGREES	TRUE HEADING

Figure 11-8 Re-generated CRT Page Display

In general terms, the program processes the information by looking up the symbol in the symbol dictionary to find its address, type, precision, scale factor, etc., as appropriate. It files the information in an eighty double-word table assigned to that particular page. This implies two things. First, the information in the symbol dictionary must be complete and accurate. Second, no more than 80 computer responses may be requested for any page.

The computer response information is placed into the table by separate schemes for numbered and unnumbered entries. Numbered entries are placed in the table from the top down in their numbered spot. The unnumbered entries are placed in the table from the bottom up according to the time order in which they are processed. It is, therefore, important that when both numbered and unnumbered computer responses appear on a page together, the numbered items start around 01 and advance through the low numbers.

11.1.7.2 Malfunctions. The FCIS training is orientated toward combat crew interactions and tactics. Malfunction capabilities should be designed to provide training in overcoming failure of, or casualties to critical systems, and the continued ability to fight quickly and effectively. Following is a list and description of system failures which impact the tactical performance capabilities of the crew and which can be remedied or worked around without dismounting.

a) Tank immobilized (engine running) - such as a broken track, or drive train component.

b) Electrical failure - (requiring sparing battery usage or manual traverse, firing and so forth).

c) F.62 coaxial machine gun jammed.

d) .50 caliber machine gun jammed.

e) Round will not fire - main gun

f) Ballistic computer failure

h) Engine failure (as a result of a hit or a fuel or oil system failure)

i) Stabilization system failure (Azimuth)

j) Stabilization system failure (Elevation)

k) Stabilization system failure (Analog drift, dc rate drift)

l) Breech hydraulic damper failure (breech hang up)

m) Main gun-no ejection, or partial ejection.

n) Safety circuit failure - main gun

o) Laser rangefinder failure

p) Intercommunications sytem failure

q) Radio failure

Malfunctions for FCIS should be both manual and automated (via preprogramming). The instructor must have the capability to manually identify, insert or remove malfunctions via display page and keyboard interaction. Since the number of FCIS malfunctions is relatively small, all malfunctions could be displayed on one page. Each malfunction would be assigned an identification number: malfunctions currently active would be designated by a symbol next to the malfunction number. Typically, malfunctions are manually inserted in one of two ways. If the malfunction number is known by the instructor, he may simply key" MALF", the malfunction number, and "INSERT". When this method is used, no display page changes will take place, thus allowing the instructor to continue monitoring the currently displayed page. Deletion of malfunctions is accomplished by keying "MALF", the malfunction number, and "DELETE". To identify malfunctions when the desired malfunction number is known, the malfunction page would be selected by keying "MALF" and "DISP". At that point the instructor needs only to key in the malfunction identification number and "INSERT".

The FCIS instructor should also have the capability to preprogram malfunctions for automatic insertion. When a mission is formulated malfunctions can be planned to occur at a particular time or when a particular set of conditions or event exists, e.g., when an enemy tank fires at own tank, the main gun round will not fire. During the mission the instructor can concentrate on his main tasks of monitoring and evaluating the crew without being distracted by the requirement to insert a malfunction at a particular time.

Conditions for malfunction insertion will be written in FORTRAN in an IF...., THEN....format. Some detail on preprogramming malfunctions is presented in section 11.1.7.4.

11.1.7.3 Record/Playback. The recommended approach to record/playback is to record inputs and selected internal variables as discussed in Section 11.1.4.2. Implementation of this approach was also described in detail in that section. Record/playback control will be provided via instructor station display and keyboard. The instructor will initiate the recording mode by activating a switch. Due to the limited duration of a typical tank engagement a recording will be automatically terminated after 1 minute. The instructor will have the capability to record thirty segments. Segments will be selected for playback from a display page. Each recorded segment will be identified by a mission elapsed time (MET) so that the instructor will have a frame of reference from which to select a segment for playback. Each recording would be automatically time tagged and entered into the first available segment identification slot on the display page along with its MET.

11.1.7.4 Problem Formulation and Control. Most of the features described in the preceding sections can be implemented automatically, during operation, using the preprogramming capability. The design objectives for this system were to provide the appropriate capabilities in such a way as to allow sophisticated research capabilities in training technology utilizing a library of automated exercises, and to allow ease of operation for users not proficient in computer programming.

To do this, two design problems must be addressed. The first is to provide a flexible system that can easily perform the required functions during real time operation, and allow new problems to be generated, or modifications made to existing problems, through the instructor's CRT and keyboard controls. The second design problem is to provide an interface language that is usable by personnel who are completely inexperienced in computer programming.

The preprogramming system should allow the user to develop a library of exercises (see Figure 11-9) where each exercise consists of a table that defines a minimum of one and a maximum of twelve exercise segments. Each exercise segment should have associated with it a table which defines a maximum of fifteen cases. The system stores exercise tables, task tables, and cases on a disk file, once they are created. This makes it very easy to modify any element within the exercise structure. When any of these elements are created, an index page assoicated with the element is updated, so the user has the capability of looking at an index of the exercise tables, exercise segment tables, or cases. After creation or modification of an exercise table, the complete exercise is compiled and cataloged (at exercise segment level). Each segment of the exercise will be resident on the disk as an object module, which is overlayable into core and executeable.

The preprogramming system consists of a group of low-priority, non-real-time foreground programs. The primary program should be interactive with the alphanumeric CRT. This program allows development of exercises and setting up specific core tables when a request is made for execution of a particular exercise. Another program has the task of performing th loading of the absolute overlays (exercise segment object code) when an exercise execution is requested.

The selection of a high order language permits the solving of most of the user interface problems. First, many of the interested users are technically-oriented instructors and are probably familiar with FORTRAN. The simplicity of much of the coding requires virtually no learning for those who might be unfamiliar with the language. The incorporation of preformatted pages can make the use even simplier. Each input page encountered by the user contains all syntax-required data as well as structured statements requiring only data that is specific to desired results.

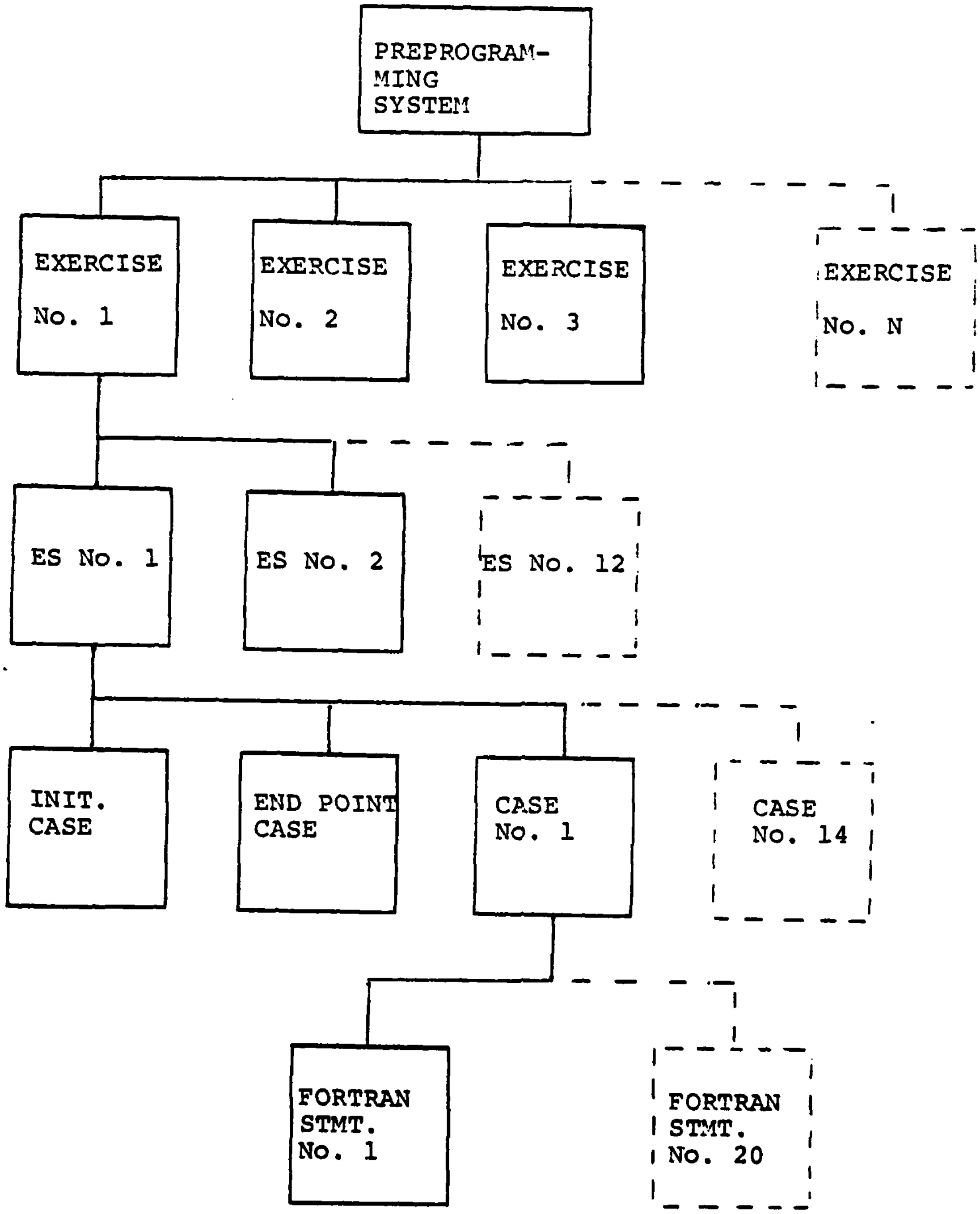

Figure 11-9 Typical Preprogramming Structure

One of the requirements noted earlier was that the system should be interactive. The system is designed to lead the user through the steps and processes required for each phase of input. During exercise generation or modification, both alphanumeric CRT's and the associated keyboard are employed. Instructions appear on one CRT, while computer requests for user inputs and user responses appear on th other CRT. All user inputs are made via the keyboard once the mode is activated.

All software inputs needed to satisfy structural aspects of the exercises are preformatted with the user entering specific data such as:

1) Record Titles: The system as mentioned is actually a series of files structured in the following hierarchy: exercise, exercise descriptions, exercise segments, and cases. Thus, each new record requires a title entered on the top two lines of the preformatted page. It should be noted that an index display is provided as part of the system. The generated titles, as mentioned above, are automatically added to the appropriate index.

2) Record Numbers: The record numbers are the pointers used by the software in the concatenation process. As each source file is generated or modified, the user enters the number.

3) File Assignments: The basic functioning syntax is usually at the case level. Files higher up in the hierarchy are constructed by assigning records of lower level files to them. An exercise segment consists of a series of up to 14 cases. Thus, to generate a segment, the coding contains only the text CASE XYZ (XYZ is the case record number). The syntax CASE references a file, and XYZ identifies the record number in that file.

4) Conditions and Actions: At the case level, the user is generating conditional statements and action statements. For the most part, this is preformatted, but when it is not, the user's guide describes the step required to perform the desired action. It should be obvious that the designers could not predict all possible combinations of condition statements and resulting actions. This much is left to the user.

11.1.7.5 Performance Monitoring and Scoring. In order to determine the appropriate performance monitoring features for the FCIS-LM device it was necessary to analyze specific tasks performed. First, the type of scenarios that the crew will be exposed to must be considered. Table 11-2 identifies several types of engagement scenarios. It should be noted that scenario time between engagements will not require extensive monitoring systems, if any, due to the nature of tasks performed. An analysis of those tasks and the types of skills required by the crew is contained in Section 4, Tables 4-2 through 4-5. This task and skill data has been used to determine the approach to FCIS-LM trainee performance assessment. The system features are also based on the twenty engagements described in Section 5 and identified in Table 11-2. Two important aspects related to crew performance assessment. First, the specific sequence of actions and their correct application to the engagement must be evaluated or recorded. The other aspect is that of total response by the integrated crew, to the problem presented.

Since the latter function requires more subjective judgement on the part of the instructor, it will be discussed first. The overall engagement objective of the M60A3 crews is to seek out, identify, and destroy enemy targets. All this must occur prior to the enemy performing the same. Ultimately then, the "true" measure of the crew's ability is to survive in the tactical environment. In order to evaluate this type of performance in the FCIS device, the entire problem must be broken down into two areas: 1) engagements and 2) non-engagements (cross country, etc.). In cross country exercises, no performance measurement is of any value except in following correct paths. The more important aspect is the end result achieved by the crew during specific enemy engagements.

In analyzing methods of measuring performance, two things emerge. First, correct performance is a function of achieving certain task objectives in the proper time frame. These are general in nature and determine survivability. One can view these procedurally; consider the following steps:

1) t_o - Target is within visual acquisition range

2) t_1 - Crew acquires target

3) t_2 - Turret turned to TGT azimuth

4) t_3 - Ranging

5) t_4 - Fire weapon round one

6) Kill/Miss

7) t_5 - Fire weapon round two

8) Kill/Miss

The goal is a first-round target hit in the minimum possible time (FM 17-12). For example, an M60-series tank moving 12-15 mph with main gun loaded and laid no more than 15° off target, range and ammunition indexed must be able to engage an armor-type target using battlesight within 5 seconds during daylight and obtain a target hit within 10 seconds.

Based on time t_5 and assuming enemy performs correctly, assessment of performance is whether a kill or miss is obtained.

Obviously, a P_k (probability of kill) would be computed for the appropriate weapon. The recommended way of portraying this to the instructor or experimenter is a tabular display page listing t_0 through t_5 and showing elapsed time. A display of this might look like the one shown in Figure 11-10.

This display shows only the results of the engagement. In order to evaluate crew skills in achieving this result, another type of performance monitoring is required; one which will identify all activities occurring during engagements. It appears that the simplest approach would be the use of a "TIME/EVENT" monitor. This feature would monitor all activities, switches, controls, etc., in the compartment and provide a time based printout of when each event occurred.

The key problem associated with each of these systems is to initiate the monitoring sequence at the appropriate point in the scenario. This can be done by time, position, or events. The first two are specific but also have serious deficiencies. In a time based system where the FCIS crew exercises flexibility and their own judgement in traversing the gaming area, it will only be on rare occasions that the tank is at the proper position for an engagement at a specified time. Thus, the resulting monitoring will be in error. Position would be somewhat more realistic; however, since the crew has the flexibility to change routes, one cannot be sure that the crew will ever reach that position. The most promising approach then is to define a set of simulator events, which could include time and position, that would accurately determine the start of an engagement.

ENGAGEMENT ASSESSMENT

TOTAL N° OF TGTS IN SCENARIO xx

TGT N° IN RANGE 1. _ _ RANGE _ _ _M BRG_DEG

2.

3.

TGT ATTACKING _ _

1. VISUAL RANGE (t_0) _ _ SEC
2. TURRET ALIGNED (t_2) _ _ SEC
3. RANGE SET (t_3)
4. ROUND ONE OFF (t_4) _ _ P_{k1} _ _ _
5. ROUND TWO OFF (t_5) P_{k2} _ _ _

SCORE _ _

Figure 11-10 Typical Scoring Display

An engagement can be considered to be underway when certain criteria are met. These are:

1) Enemy target objective(s) are within visual range and not occulted.

2) The threat imposed by the objective is serious enough to warrant response.

The use of a simulated visual scene poses serious problems in making the first determination above. This is because occulting information is not easily available from the data base. The flow chart shown in Figure 11-11 represents an approach to solving this problem.

Once the start of an engagement is defined (or computed), the two performance measurement schemes can be activated.

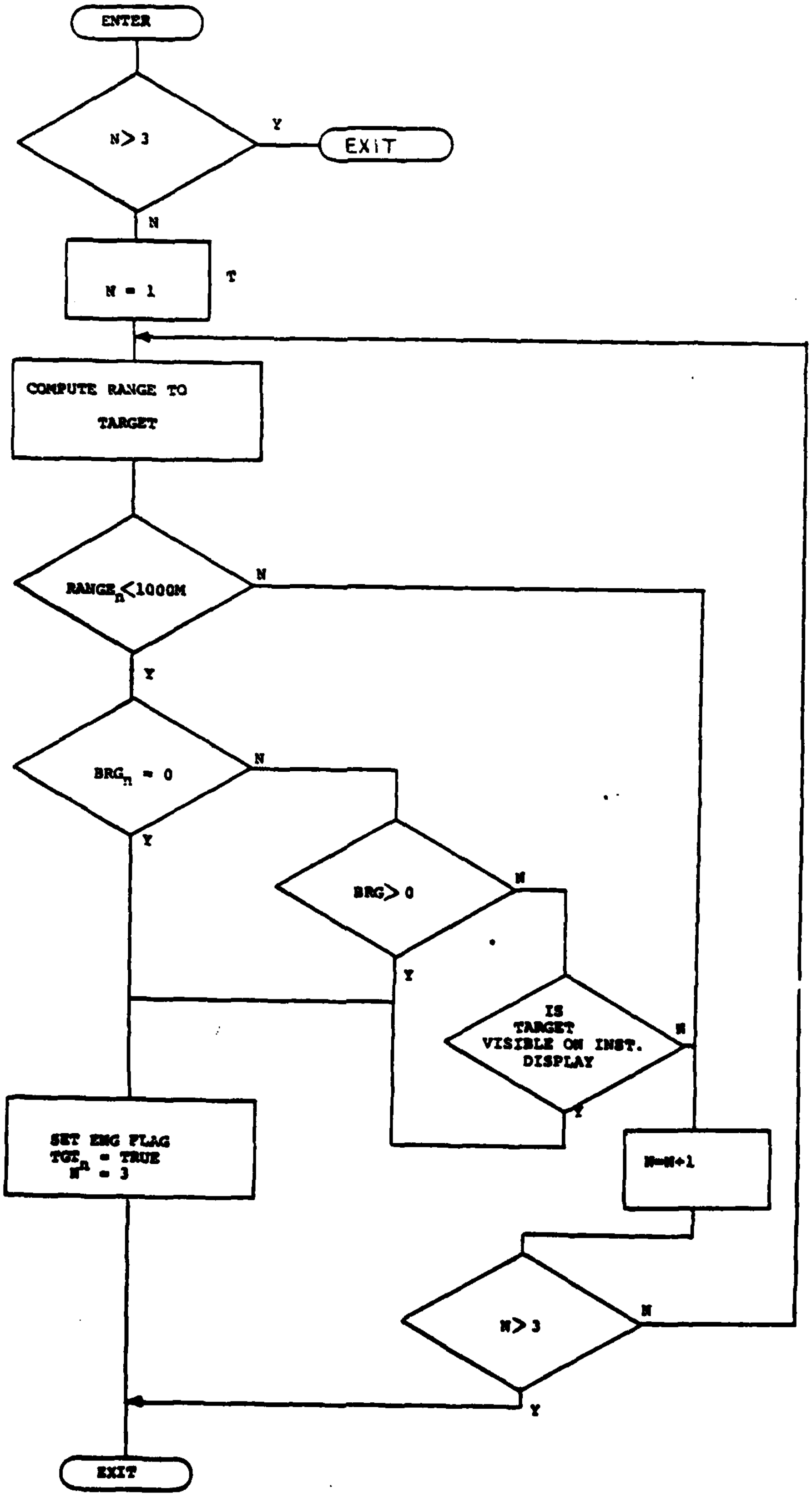

Figure 11-11 Performance Monitoring Start of Engagement Flow Chart

11.2 Computational Systems

The computation system requirements have been established for visual systems, motion systems, crew station, vehicle systems, weapons system, and instructional systems. Based on analyses of crew tasks, tactical environment, available cue(s), and the vehicle performance envelope, the real-time system requirements, and the additional computer requirements for executive programs, test and diagnostic programs, and off-line programs, can be satisfied by a multitude of computer hardware configurations ranging from one very large processor to a series of minicomputers connected in a multi-processor or multi-computer configuration. Practically all large, real-time, training simulators use combinations of computers to provide adequate computing power for the total task. It is anticipated that, in the future, computer configurations will expand on this trend by combining processors of various types of minimize problems such as time-lag between control input and system response, and to provide a better match of processor power versus individual system computing tasks.

An example of this is the NASA Orbiter Aero-Flight Simulator system, which employs one medium size computer for basic computation, background, and off-line batch processing; and separate mini computers to handle motion system, visual system, real-time input/output, and space shuttle onboard computer interfaces. Such a system could be expanded further to include micro-processors for additional special applications such as linear function interpolation (LFI), fixed/float conversions, or other data formatting tasks, or to handle special peripheral devices.

This approach provides major benefits of greater computing power and flexibility at lower overall cost than can be obtained with a single large computer. This approach is especially true in the light of the recent introduction of powerful and relatively inexpensive micro-programmable 32-bit minicomputers and other inexpensive micro-programmable devices which may be used as building blocks in a large real-time computation system as required for the FCIS.

11.2.1 Computation System Accuracy and Resolution. Most mini-computers are designed for 16-bit data and hence use 16-bit instruction word lengths. However, 16-bit architecture has limitations if large programs are required, or if large arrays of data require manipulation, as in scientific, engineering, simulation, or business data processing. The present estimates of FCIS-LM computer instructions plus data indicate that approximately 435K bytes of memory are required for resident real-time software (not including spare). This exceeds the capacity of most 16-bit computers. Hence, if 16-bit computers were to be used on the FCIS-LM, special addressing and data file techniques organization would be required. The use of a 24-bit or 32-bit computer frees the FCIS-LM from this limitation. The task of breaking up large programs to fit a small computer is eliminated. A 32-bit computer also has other advantages not found in a 16-bit machine, including the opportunity to increase compiler efficiency through the higher speed of a single-precision, 32-bit and double-precision, 64-bit floating-point processing.

These attributes, and the tradeoff cost comparisons between 16-bit and 32-bit computers of similar speed, have led to the recommendation to use a 32-bit computer.

11.2.2 Computation Software. The software for a simulator in a multi-processor configuration is typically divided among each processor according to the tasks to be performed. The partitioning process is usually accomplished using module size and instruction timing estimates as guides. This procedure is sometimes supplemented by conducting bench-mark tests on the equipment to determine actual performance characteristics, spare time, and core. Typically, the design of a simulator computer system is an iterative process. Certain portions of the hardware and software are designed independently, but the remaining portions must be considered interactively. Currently, there are two methods of partitioning software on a multi-processor system. If the hardware configuration is designed first, it will dictate, to a large degree, the allocation of real-time software tasks. Alternately, an optimum software partitioning scheme might be devised first and the hardware designed and configured around it. However, in order to take maximum advantage of the benefits of a multi-processor configuration, the software partitioning required is the total computation job divided into separate, independent tasks. Since some functions are time-dependent on other functions, they must be handled in series, rather than in parallel processors.

However, the majority of functions within a simulator can be partitioned effectively in a multiprocessor system where programs can execute in a series-parallel manner without negative effects due to temporal relationships.

11.2.2.1 Software Design Methodology. For more than a decade, simulation software design methodology has evolved from the brute force-machine language approaches of the early sixties, to the use of available present-day methodologies including forms such as:

- Structured Design
- Logical Construction of Programs
- Higher Order Software
- The Jackson Methodology
- Meta Step Wise Refinement.

These new design approaches and programming concepts have been paralleled by the development of programming languages including assemblers, meta-assemblers and support software, and higher order languages such as APL, BASIC, PL/1, FORTRAN, COBOL, RPG, and others.

11.2.2.2 Higher Order Languages. The desirability of using higher-order languages (HOL's) for real-time simulation is well accepted now that their use is justified by the price and performance of computer hardware. Desirable features of HOL's include ease of training, ease of programming, faster generation of code (lower development cost), standardization of user software, self-documenting code, and fewer development errors. In the past, problems associated with using existing HOL's for simulation have included compiler inefficiencies, lack of large datapool support, lack of features such as bit and character manipulation, and lack of debugging and maintenance aids.

Recent computer hardware advancements — e.g., faster, low-cost memories and processors; large, inexpensive disks; fast, floating-point processors; and parallel processing — have opened many new doors in the area of real-time simulation. These doors include the ability to use higher order language and multitask operating systems in real-time. However, required software tools, including compilers, are only now coming of age. Due to the lag in the development of support software, a number of problems arise when using existing HOL's in simulator systems. These problems fall in the areas of: documentation for maintainability, datapool support, movement of code by optimizers, module reliability, fault isolation, bit manipulation, software change turnaround time, subroutine time and memory overhead, configuration/change control, portability between computers, and common character representation/manipulation. These problems require that the user have a knowledge of both the HOL and assembler language for each computer manufacturer. All of these problems can be (and have been) overcome.

Ideally, a well-defined higher order language (HOL), specifically designed for real-time simulation, is required. This language should be specified in terms of the simulation environment, with features included to satisfy the various design and programming tasks which arise in the development and maintenance of simulation software. The major goal for any higher order language considered for a real-time simulation environment is the efficient use of both human and hardware resources. Readability and writeability of the language constructs should minimize development and maintenance time. The language must have external options in the compiler, to make it possible to take advantage of hardware features such as parallel processors and firmware (floating point, trignometric features, and function interpretation), without modifying the user's source code.

Even though HOL's have many advantages over assembly language, they give rise to problems in the areas of:

- Increased memory and time usage
- Compiler reliability
- Module interfaces inefficiencies
- Large datapool support
- Debugging and verifying
- I/O
- Character and bit manipulation
- Function/subroutine efficiency.

Also, there are certain types of simulation programs which pose problems in specifying a HOL. These programs include the executive, I/O handlers, schedulers, debugging aids, and display processors. Each of these and other types of programs must be analyzed in detail, and tradeoffs must be made as necessary in specifying the features required to handle the problems defined. Certain processes may not be practical to include in the simulation higher order languages (SHOL) because of cost and implementation factors.

11.2.3 Computer Resource Requirements. The analysis of FCIS-LM computer resource requirements included a determination of all real-time, on-line and off-line software and associated computer and peripheral equipments required to support the armor crew training tasks. Also considered were those additional computational elements required of a laboratory-type device where additional training programs and program modifications will be developed by the user during the life of the simulator.

These computational systems requirements have evolved during the course of the study where tradeoffs were made in several system areas (i.e., visual, crew station, vehicle systems, motion systems, instructor station) relative to the hardware and software required to provide each specific simulator function.

During these system optimization procedures, individual subsystem real-time program module accuracy, computational speed, and instruction and data requirements also were determined.

The overall computation system requirement, including special processing requirements such as visual image generation, special micro-processor requirements, and analog or hybrid computers has been studied. To date, the analysis has determined that no special high-precision analog or hybrid computational elements are required for the FCIS-LM.

In order to properly evaluate various candidate computer systems, a selection model was prepared. This model provides one set of criteria common to the evaluation process for each candidate. The elements within this model are identified in Table 11-5.

Candidate computer systems were established by using available computer manufacturer data.

TABLE 11-5 DIGITAL COMPUTATIONAL SYSTEM EVALUATION CRITERIA

- Computational speed
- Accuracy
- Reliability
- Maintainability
- Operability
- Simplicity of Design
- Cost
- Compiler Efficiency
- Operating System
- Support Software

The tradeoff analysis for the FCIS-LM digital computer system considered the following computers:

- Amdahl 470/V6
- Univac 1100/43
- Interdata 8/32
- SEL 32/75, 32/55
- Digital Equipment Corporation (DEC) VAX 11/780
- IBM 370/168-I.

During the study, Link has determined that the FCIS-LM requires a system capable of executing the equivalent of at least 1.3 seconds for the foreground, plus foreground spare and operating system overhead. Table 11-6 provides a breakdown by system, detailing the requirement. Additional off-line and background program requirements are shown in Table 11-7. Disc loading requirements are summarized in Table 11-8.

11.2.3.1 Computation Speed. Link's approach in evaluating CPU computation speed was to take a simulation benchmark program and execute this on each computer system under evaluation. During the summer of 1977, the benchmark was successfully evaluated on the following systems:

- o Amdahl 470/V6 - Texas A & M University
- o IBM 370/168-I - Gaithersburg, Maryland
- o Univac 1100 - Houston, Texas.

The MIPS ratings determined for each system are shown below:

1) Amdahl 470/V6 - 2.8 MIPS
2) IBM 370/168-I - 3.6 MIPS
3) Univac 1100/42 - 1.6 MIPS/CAU (0.38 MOP's + 0.369 MOP's).

All computers evaluated either meet or exceed the FCIS-LM computational speed requirements. At the time that these minicomputer systems were evaluated, the Interdata 8/32, SEL 32/75, and the DEC VAX 11/780 minicomputer systems could not be evaluated completely. However, subsequent evaluations were made of these latter three systems using both simulation mix and benchmark runs have shown that these systems also meet the FCIS-LM requirements. Evaluation results indicate that the Amdahl 470/V6, Univac 1100/43, and IBM 370 series computers are not cost effective in meeting the FCIS-LM requirements. Thus, the selection process leaves only the Interdata 8/32, SEL 32/75, and the DEC VAX 11/780 systems.

Two of these machines, the SEL System 32/55 and the Interdata 8/32, are now in use on simulators which have been delivered by Link. Each of the three manufacturers have proven responsive to the needs of the real-time processing market and has rendered excellent support to Link. It is expected that all three manufacturers will continue, in the foreseeable future, to be among the leading suppliers of machines of this type.

The Digital Equipment Corporation VAX 11/780 has just been announced by DEC and is scheduled to be available in the third quarter of 1978.

PROGRAM MODULE	DESCRIPTION	ITERATIONS PER SECOND	MEMORY (BYTES) INSTRUCTIONS	DATA	EXECUTION TIME (MILLISECONDS) PER PASS	PER SECOND	LANGUAGE
CPU 1 PRIVATE EXECUTIVE:							
LRTM	Link Real-Time Monitor	30.0	16,776		1.173	35.19	Assembly
RTEXEC	Real-Time Executive	30.0	28,600		1.200	36.00	Mixed
	Library	On Demand	4,970	-	-	-	Mixed
SYSTEM SIMULATION:							
	Equations of Motion	30.0	6,000	1,456	2.79	83.7	Fortran
	Power Plant	7.5	1,200	800	.558	4.185	Fortran
	Suspension	30.0	1,500	400	.698	20.94	Fortran
	Electrical System	7.5	1,000	60	.329	2.468	Fortran
	Fuel System	7.5	1,200	72	.395	2.962	Fortran
	Hydraulics	7.5	1,200	12	.066	.495	Fortran
	Azimuth/Elevation Control	30	1,000	60	.329	9.87	Fortran
	Gun Control	15	800	48	.263	3.945	Fortran
	Engine Indicators	15	400	24	.131	1.965	Fortran
	Miscellaneous Subsystems	7.5	800	48	.263	1.9725	Fortran
	Aural Cues	15	8,000	480	2.635	39.53	Fortran
	Motion, Driver Station	30	2,640	80	.930	27.90	Fortran
	Motion, Fighting Station	30	inc. (1)	80	.930	27.90	Fortran
	Audio Control	30	576	120	.223	6.690	Fortran
	Communication Power & Switch Logic	15	864	180	.334	5.010	Fortran
	Visual System Interface	30	4,400	1,230	2.046	61.38	Fortran
	Visual Binocular Sensor	30	800	40	.837	25.11	Fortran
	Visual Smoke Control Unit	30	4,600	100	1.860	55.80	Fortran

TABLE 11-6 FCIS-LM COMPUTER REAL-TIME MEMORY REQUIREMENTS pg 1 of 4

PROGRAM MODULE	DESCRIPTION	ITERATIONS PER SECOND	MEMORY (BYTES) INSTRUCTIONS	DATA	EXECUTION TIME (MILLISECONDS) PER PASS	PER SECOND	LANGUAGE
CPU 1 Private Executive:							
	Main Gun Flash	30	400	20	.140	4.20	Fortran
	Night Viewing Sensor	30	400	60	.558	16.74	Fortran
CPU 1 Private:							
Subtotal:			88,126	5,370		473.95	
TOTAL PROVIDED:			262,144			1,000	
SPARE REQUIRED:			131,072			500	
SPARE AVAILABLE:			174,018			526.05	
CPU 2 Private Executive:							
	Slave Real-Time Monitor	30	6,704		1.173	35.19	Assembly
	Real-Time Executive	30	28,600		1.200	36.0	Mixed
	Library		4,970				Mixed
System Simulation							
	Ballistic Computer	30	8,000	400	3.12	93.60	Fortran
	Relative Target Position Monitor	7.5	1,800	60	.581	4.36	Fortran
	Laser Range Finder	30	2,400	80	0.775	23.25	Fortran
	Turret/Cupola Attitude	30	12,000	500	4.65	139.50	Fortran

TABLE 11-6 FCIS-LM COMPUTER REAL-TIME MEMORY REQUIREMENTS pg 2 of 4

PROGRAM MODULE	DESCRIPTION	ITERATIONS PER SECOND	MEMORY (BYTES) INSTRUCTIONS	DATA	EXECUTION TIME (MILLISECONDS) PER PASS	PER SECOND	LANGUAGE
	Projectile Trajectory	30	4,000	200	4.03	120.90	Fortran
	Trajectory Integration S/R		720	20	.279	inc. (2)	Fortran
CPU 2 Private:							
Subtotal:			69,194			452.79	
TOTAL PROVIDED:			262,144			1000.	
SPARE REQUIRED:			131,072			500.	
SPARE AVAILABLE:			192,950			547.21	
CPU 3 Private Executive:							
	O/S 32 MT	30	64,000		3.500	105.00	Assembly
	Real-Time Executive	30	28,600		1.200	36.00	Mixed
	Library	On Demand	13,672		–	–	Mixed
Instructional Features:							
M501	Malfunction Control	3.75	7,980	130	2.000	7.500	Fortran
S501	Display Handler	As Required	1,600	200	.336	-	Assembly
S502	Function Keyboard Handler	As Required	800	100	.168	-	Assembly
S503	Display Conversion	3.75	22,000	26,000	12.000	45.00	Mixed
S504	Map Control	As Required	3,400	120	.300	-	Fortran
S505	Map Plotter	3.75	13,580	1,100	2.500	9.375	Fortran
S506	Alpha Keyboard Handler	As Required	800	100	.200	-	Assembly
U501	Function Keyboard Interpreter	3.75	1,352	900	6.00	22.50	Fortran

TABLE 11-6 FCIS-LM COMPUTER REAL-TIME MEMORY REQUIREMENTS pg 3 of 4

PROGRAM MODULE	DESCRIPTION	ITERATIONS PER SECOND	MEMORY (BYTES) INSTRUCTIONS	DATA	EXECUTION TIME (MILLISECONDS) PER PASS	PER SECOND	LANGUAGE
CPU 3 Private	(cont'd)						
U502	Initial Conditions	As Required	3,200	1,550	.050	-	Fortran
U503	Hard Copy Data	As Required	4,800	2,000	.200	-	Fortran
U504	Hard Copy Output	As Required	4,800	2,000	.200	-	Fortran
W501	Exercise Monitor	3.75	1,400	100	2.500	9.375	Fortran
W511	Exercise Overlay	0	3,600	0	0	0	Fortran
W502	Parameter Recording	30	3,000	200	.100	3.000	Fortran
X501	Demo/Record/Playback	30	24,000	16,800	3.000	90.000	Mixed
X502	Demonstration Audio	7.5	5,760	700	2.500	18.750	Mixed
Y501	Performance Monitor	1.875	4,000	100	1,000	1.875	Fortran
Y511	Performance Monitor Overlay	0	4,000	0	0	0	Fortran
CPU 3 Private:							
Subtotal:			216,344	52,100		348.40	
TOTAL PROVIDED:			524,288			1000	
SPARE REQUIRED:			262,144			500	
SPARE AVAILABLE:			307,944			651.60	
SHARED MEMORY - COMMON DATA							
Shared Memory				58,730			
RTIO Data				484			
Total Required:				59,214			
TOTAL PROVIDED:				131,072			
SPARE REQUIRED:				65,536			
SPARE AVAILABLE:				71,858			

TABLE 11-6 FCIS-LM COMPUTER REAL-TIME MEMORY REQUIREMENTS pg 4 of 4

PROGRAM MODULE	DESCRIPTION	MEMORY (BYTES) INSTRUCTIONS	DATA
	Fortran Compiler	64,000	
T501	Map Generator	70,000	10,000
T502	Page Generator	35,000	60,000
T503	Exercise & Analysis Formulation	40,000	50,000
T504	Data Analysis	10,000	50,000
T514	Data Analysis Overlay	10,000	-
MTS	Maintenance and Test System	106,457	
SDS	Symbol Dictionary System	70,246	
SMS	Source Modification System	20,645	
CONC	Symbol Concordance	9,732	
SORT	General Purpose Sort	15,352	
OVLLIB	Overlay Librarian	9,472	
SCS	Software Control System	51,206	
SUS	Source Update System	23,444	
AFLOW	Auto Flow Charting System	64,906	
DEBUG	Real-Time Debug	59,030	
TSKGEN	Task Generator	20,056	
COMGEN	Common Generator	3,896	
PI20	Utilities	1,364	

TABLE 11-7 COMPUTER OFF-LINE AND BACKGROUND MEMORY REQUIREMENTS

PROGRAMS	DATA K-BYTES	REAL-TIME ACCESSES/MINUTE	BYTES/ACCESS	K-BYTES/MINUTE
Instructional Features Programs	19,920	60	18,000	1,080
Real-Time Loads	360	-	-	-
Support Programs	2,000	-	-	-
Vendor Operating System	400	-	-	-
Fortran Compiler	900	-	-	-
Utilities	1,200	-	-	-
CALMACRO Source	800	-	-	-
CALMACRO Object	500	-	-	-
O/S Source	1,500	-	-	-
TOTAL	27,580	60	18,000	1,080

TABLE 11-8 FCIS-LM DISK LOADING REQUIREMENTS

11.2.4 Computer Peripheral Requirements. Peripheral equipment is required to support the digital computer system in both real-time training modes and background batch processing and data processing activities.

For real-time simulation program support, a disk controller and drive are required. This disk system provides basic requirements for on-line mass storage of all real-time simulation programs and data, and also stores all of the off-line utility and diagnostic programs. A back-up disk drive is recommended so that, in the event of the primary disk failure, it shall be possible to continue training operations with a minimum of interruption. A computer terminal with a hard copy output device also is recommended. This terminal will function at the primary console for control of the computer operating system. Support peripherals are recommended to allow software support functions. These include, as a minimum:

- A 400 cpm card reader and interface controller
- A 600 lpm line printer and controller
- An IBM 029 interpreting keypunch
- A dual 9-track magnetic tape unit and controller.

11.2.5 Computer Program Requirements

11.2.5.1 Software Design Approaches. Of the software design methodologies mentioned previously, structured design is the most familiar in the simulation world. The Jackson Methodology and LCP are primarily business oriented. The MSR implies an iterative process of program development that requires an exact fixed problem definition. It works most effectively in a solution involving only a single module where an elegant solution is desired (e.g., the executive program for an operating system). It produces a level-structured, tree-structured program. Higher Order Software, in this context, is a new programming language being used on the NASA Space Shuttle program. Compiler and support software are not available for most of the commercially available computers considered for the FCIS-LM. For the FCIS-LM a Structured Software Design methodology, which includes top-down programming concepts, is recommended. This methodology consists of concepts, measures, analysis techniques, guidelines, rules of thumb notation, and terminology.

Reliance is placed upon following the flow of data through the system to formulate program design. The interpretation of the system specification is used to produce a data flow diagram and structure chart. The design process usually is iterative. Identifying incoming and outgoing data flow boundaries are used to define modules and their relation ships; however, the boundaries of the modules can be redefined almost arbitrarily.

The methodology works best where input data can be transformed into outputs in incremental, easy to follow steps.

This method, therefore, is well suited to design problems such as the FCIS-LM, where a well defined data flow can be derived from the problem specifications. Input and output data are, or can be made, well distinguished from each other, and data transformations are done in incremental steps.

11.2.5.2 Programming Language. For the FCIS-LM, programming languages, including Assembler, FORTRAN, PL/1, APL, and BASIC, have been evaluated against the present and long-term requirements of the program. These languages have been compared using the following criteria:

- o Program efficiency
- o Programmer acceptability/training requirements
- o Computer efficiency
- o Transportability between different computers
- o Maintenance and documentation features
- o Ability to meet future requirements
- o Life cycle cost.

None of the computer manufacturers considered as finalists for the FCIS-LM provide APL or PL/1 compilers or support software. BASIC is severely restricted by the limitations on naming of data, data base structures, program size, and compiler efficiency.

The only HOL which successfully meets all of the criteria is FORTRAN. This language has been used successfully on large scale simulators such as the NASA Skylab and Space Shuttle, the Air Force SAAC and ASUPT, and the Navy F-14 and AWAVS. Therefore, it is recommended for use on the FCIS-LM.

It also should be noted that DOD Instruction 5000.31 allows only FORTRAN as an interim HOL.

11.2.5.3 Real-Time Programs. Real-time computer programs include those categorized as executive programs, synchronous application programs (which simulate the vehicle dynamics and M60 subsystems), motion systems programs, and those classified as advanced training programs.

11.2.5.3.1 Executive Programs. The following programs considered in the executive class are required:

Supervisor Real-Time Executive - An executive program is required in each simulator computer to provide simulator synchronization and control processing in consonance with the resident real-time operating system. Functions coordinated by the real-time executive should include disk access methods, overlay loading, master-slave CPU synchronization, and operator communications.

Input/Output - Real-time input/output programs are required to control data traffic to and from various devices such as signal conversion equipment, the printer plotter, CRT displays, visual equipment, and remote computer control units and digital readout units (DRU's).

Closed-Loop Linkage Test - Programs to operate in simulator background time are required to test and monitor the status of the signal conversion equipment (SCE). These programs should monitor output channels and test input channels in the spare I/O time available between real-time system I/O updates. Output of error messages should be sent to the CRT/terminal and a hand copy device.

Subroutines Library - A library of mathematical procedures is required which includes a numerical integration routine, and standard procedures such as limits, linear function interpolation and trigonometric functions.

11.2.5.3.2 Synchronous Application Programs - A summary of all real-time programs along with the iteration rates are given in Table 11-6.

11.2.5.3.3 Motion System Programs. The motion system provides the physical cues resulting from vehicle maneuvers. The vehicle dynamics software provides the inputs to the motion system software which consists of:

- o Primary motion cue generation software
- o Geometric transformation software
- o Special effects software.

11.2.5.3.4 Advanced Training Programs. Advanced Training software has four basic categories:

- STATUS - These routines present the status of the simulator to the instructor and the experimenter. Status/control pages and the Vehicle Position Chart are presented on the IES displays, and the hardcopy routines provide a permanent record of these pages when required.

- CONTROL - Control of the simulator is provided by these routines, which include malfunctions, initial conditions, dynamic replay, the exercise monitor, and general controls such as those implemented by editing the status/control pages. Also included as control routines are the keyboard handlers and interpreters, as the function keyboard gives the instructor control of routines in all categories, and the alphanumeric keyboard gives the experimenter his own additional control capability.

- EVALUATION - Trainee proficiency is evaluated through the use of such routines as Performance Measurement, Exercise Monitor, and Data Analysis. These routines can all be modified by the support routines, as required to suit new missions, various trainee proficiency levels, experimentation requirements, etc.

- SUPPORT - These routines support the routines in the other categories. Three are off-line routines: Map (Vehicle Position Chart) Generation, Page Generation, and Exercise & Analysis Formulation. The one on-line routine is Parameter Recording, which is used primarily by the experimenter.

Both the instructor and experimenter use all of these routines, with the experimenter using the support routines to control his experimentation. Some routines fit into more than one category, such as the status/control pages and the exercise monitor. In the same manner, many basic routines, with their capabilities modified by the support routines, provide powerful experimentation tools.

11.2.5.4 Off-Line Programs. Off-line programs include:

- o Simulation Support Programs
- o Computer System Support Programs
- o Maintenance and Test Programs
- o Calibration Test Programs
- o Utility Support Programs.

Simulator support programs are required to verify cycle time, perform pre-mission checks, and to provide mission support for alphanumeric/graphic CRT display generation. Computer system support programs are required to support the operating system, control peripheral equipments, support software development, loading, and test. Memory dump, copy and trace, and special mathematical library software are included in this category:

Maintenance and test programs are required to test fully the crew station system, associated interface equipment, signal conversion equipment, and computer peripherals. Calibration test programs are required to check the accuracy and flow of all signals between the computer and all external simulator signal sources and terminations.

Utility support programs, including an assembler, compiler, trace routines, simulator verification routines, data base support programs, simulation system update, and modification control routines are required.

11.2.6 Computer Selection. The FCIS-LM computer choice has impact over a considerable period of time if follow-on simulators for in-field training are considered. Procurements could occur over a period of several years or longer. It is recognized that this kind of longevity is of great concern to the FCIS-LM user. Therefore, every effort must be made to select a computer system which will not become obsolete during the life of the program. As mentioned previously, a large number of computer models were considered, based upon the requirements which have evolved for the FCIS-LM. The three candidates which were shown to be most cost effective are the:

Interdata 8/32

SEL System 32

DEC VAX 11/780.

Two of these machines, the SEL System 32 and the Interdata 8/32, are now in use on simulators which have been delivered by Link. The Digital Equipment Corporation VAX 11/780 has been announced by DEC and is scheduled to be available in the third quarter of 1978. Each of the three manufacturers has proven responsive to the needs of the real-time processing market and has rendered excellent support to Link. It is expected that all three manufacturers will continue, in the foreseeable future, to be among the leading suppliers of machines suitable for real-time training simulation applications.

Of these three, Interdata and SEL were selected as the finalists for this study. The primary reasons for eliminating the DEC VAX 11/780 at this time are (a) the lack of availability of a multi-port memory, (b) the requirement for extensive development of new real-time executive and support software, and (c) higher hardware costs.

11.2.6.1 Software Feature Comparison. The features of operating system, support software, and FORTRAN were compared for both Interdata and SEL. The SEL RTM has been in use since 1969 while the Interdata OS/32MT has been in use since 1975. Both operating systems have been used in building simulation systems; both systems have adapted well to the areas of program development and real-time; both systems have been accepted by the government; therefore, both systems are judged to be equivalent. Similarly, the SEL FORTRAN has been in use since 1969 while the Interdata FORTRAN has been in use since 1977. Nonetheless, both compilers have been used extensively without difficulty and, thereby, are deemed equivalent.

A table of features for the software area is prepared below:

OPERATING SYSTEM	INTERDATA	SEL
Real Time Features	X	X
Multi-tasking	X	X
Overlay Capability	X	X
File Structure	X	X
Resource Management	X	X
Multi-terminal	X	X
Foreground/Background	X	X
SUPPORT SOFTWARE		
Copy	X	X
Trace	X	X
Editors	X	X
Debug	X	X
Math Library	X	X
Microcode Math Library	X	N
Loaders	X	X
Assemblers	X	X

FORTRAN	INTERDATA	SEL
ANSi 3.9 Standard	X	X
ISA Extensions	X	X
Optimizations	X	X
In Line Code	X	X
Conditional Compilations	X	X
Run Time Debug	X	X
OS Integrated	X	X

11.2.6.2 Hardware Feature Comparison. The hardware features of the INTERDATA 8/32, the SEL 32/55 and the SEL 32/75 are tabulated below. The features listed are all relevant to simulator system architecture.

CENTRAL PROCESSOR	Interdata 8/32	SEL 32/55	SEL 32/75
Priority Interupts	X	X	X
Multiple Register Sets	X	-	-
Concurrent I/O	X	X	X
Independent I/O	X	X	X
Large Memory Direct Addressing	X	X	X
High Speed DMA	X	X	X
Precision Timer	X	X	X
Wide Instruction Set	X	X	X
Bootstrap	X	X	X
Indirect Addressing	-	X	X
Indexing	X	X	X
OPTIONS			
Writable Control Store	X	-	X
High Speed Floating Point	X	-	X
Multiport Shared Memory	X	X	X
Microprogrammed I/O Device	-	X	X
PERIPHERALS			
Large Moving Head Discs	X	X	X
High Speed Magnetic Tapes	X	X	X

With the exception of the multiple register sets, the CPU's are feature-comparable. Multiple register sets can be used to reduce context switch time if required. The INTERDATA 8/32 and the SEL 32/75 offer the same options as illustrated above. All computers offer the same basic peripherals. The SEL 32/75, in light of the need for the options listed above, is clearly preferred over the SEL 32/55 for FCIS-LM. The INTERDATA 8/32 system with the above options has been in use for almost two years. The SEL 32/75 with the same options is yet to be made available for delivery. It must be concluded, therefore, that the INTERDATA 8/32 computer offers an advantage in the FCIS-LM system.

11.2.6.3 System Performance. A large measure of any computer selection decision is the extent to which hardware and software combine to provide overall computer system performance. The measurement of system performance is accomplished through the execution of benchmarks, architected for use in a simulation environment.

a. Simulation Mix. The first benchmark (Table 11-9) measures CPU speed as a function of an instruction set derived from simulation programs developed by Link. This mix provides a relative measure of each computer's hardware execution speeds.

	Average Instruction Time
INTERDATA 8/32	1.55 (seconds)
SEL 32/75	1.65

b. KOPBM. The second benchmark has been provided by NASA and is prepared in FORTRAN and tests compiler efficiency as well as CPU speed. The results of that benchmark are listed below. Although the results are presented in MOPS (millions of operations per second), which are difficult to translate to MIPS, they do present a relative measure of system performance.

INTERDATA 8/32	0.215 MOPS
SEL 32/75	0.161 MOPS

One can conclude that, since the Simulation Mix results are very close, the INTERDATA 8/32 FORTRAN system was able to optimize highly the KOPBM test and account for the large relative difference.

c. ACMS. The third benchmark was provided by the Navy in the ACMS REP. The F101 test is mainly arithmetic, the L127N is a test of non-indexed logical operations. The L127I is an indexed version of the L127N test. It is difficult to place weights to the values of the three tests other than to say that typical simulator problems are usually more than 33% arithmetic. The table below lists execution time in microseconds.

	F101	L127N	L127I
INTERDATA 8/32	623	381	444
SEL 32/75	762	393	407

TABLE 11-9 INSTRUCTION MIX AND INSTRUCTION TIME COMPARISON

			INTERDATA		SEL 32/75	
DESCRIPTION	TYPE	PERCENT OF OCCURRENCE	EXECUTION TIME (US)	WEIGHTED TIME (US)	EXECUTION TIME (US)	WEIGHTED TIME (US)
Fixed-Point Load	Register - Memory	10.1	1.25	0.126	1.2	.1212
Fixed-Point Load	Register - Register	4.8	0.40	0.019	0.6	.0288
Fixed-Point Store	Memory - Register	3.9	1.25	0.049	1.2	.0468
Fixed-Point Multiply	Register - Register X Memory	0.3	4.50	0.014	6.0	.018
Floating-Point Load	Register - Memory	13.4	1.47	0.197	1.2	.1608
Floating-Point Load	Register - Register	7.2	1.04	0.075	0.6	.0432
Floating-Point Store	Memory - Register	11.2	2.31	0.259	1.2	.1344
Floating-Point Add/Subtract	Register - Register ± Memory	7.4	2.10	0.155	1.95	.1443
Floating-Point Add/Subtract	Register - Register ± Register	6.4	1.20	0.077	1.95	.1248
Floating-Point Multiply	Register - Register X Memory	8.6	2.68	0.230	3.95	.3397
Floating-Point Multiply	Register - Register X Register	5.7	1.85	0.105	3.95	.2251

TABLE 11-9 INSTRUCTION MIX AND INSTRUCTION TIME COMPARISON (CONT'D)

			INTERDATA		SEL 32/75	
DESCRIPTION	TYPE	PERCENT OF OCCURRENCE	EXECUTION TIME (US)	WEIGHTED TIME (US)	EXECUTION TIME (US)	WEIGHTED TIME (US)
Floating-Point Divide	Register - Register ÷ Memory	0.3	4.63	0.014	4.2	.0126
Logical	Register - Register (Operation) Memory	2.0	1.25	0.025	1.2	.0240
Logical	Register - Register (Operation) Register	4.8	0.40	0.019	1.6	.0288
Compare	Register with Memory	0.6	1.98	0.012	1.2	.0072
Compare	Register with Register	1.2	1.28	0.015	.6	.0072
Branch		11.4	1.15	0.131	1.2	.1368
Other		0.7	4.00	0.028	1.2	.0084
TOTAL				1.550		1.6120

The core memory object code requirements virtually were the same for all systems. The benchmarks were constructed such that little, if any, structural optimization could be accomplished.

d. Conclusion. In actual system performance, benchmarks KOPBM, and ACMS, the INTERDATA 8/32 out-performed the SEL 32/75. The INTERDATA 8/32 system thereby offers an advantage in overall capability at costs which have been computed as comparable. Benchmark results have been provided as an attachment to this study manuscript.

11.2.6.4 Final Selection. On the basis of the aforementioned comparisons, the SEL System 32 and the INTERDATA 8/32 have equivalent software, but the INTERDATA 8/32 system provides a hardware advantage and a systems performance advantage. Therefore, the INTERDATA 8/32 system is selected over the SEL System 32 for the FCIS-LM.

The previous discussions related to technical issues only. However, it should be pointed out that, of the finalists considered for this selection, the INTERDATA 8/32 is the only computer system currently in the U.S. Army inventory. The INTERDATA 8/32 currently is used on two BLACKHAWK programs, the helicopter program and the digital visual system program. Both of these 8/32 systems are configured almost identically to that recommended for the FCIS-LM. Familiarity and current use of this configuration leads to a minimum risk approach to the computer area. Computer hardware commonality is a fallout from the selection of INTERDATA 8/32 for FCIS-LM.

The recommended FCIS-LM computational system is shown in Figure 11-12. A three-CPU Multiprocessor system is required to satisfy the real-time program and spare requirements. One processor is configured with 512K bytes of 750-nanosecond core memory; the second and third with 256K bytes. In addition, a 128K byte shared memory is incorporated.

Each of the central processors also is equipped with a high-speed, floating-point arithmetic unit and a 2048-word writeable control store option. The basic peripheral units include an 80-megabyte moving-head cartridge-disk system, a backup 80-megabyte disk drive, an Interdata Carousel 30 for use as an operator console, and a CRT Terminal display keyboard and hard copy system. The writeable control stores will be programmed with the FORTRAN run time library to enhance throughput.

In addition, a 1000 cpm card reader, a 600 lpm line printer and an interpreting keypunch are provided for software support operations. The 1000-cpm card reader is recommended to achieve added throughput capability.

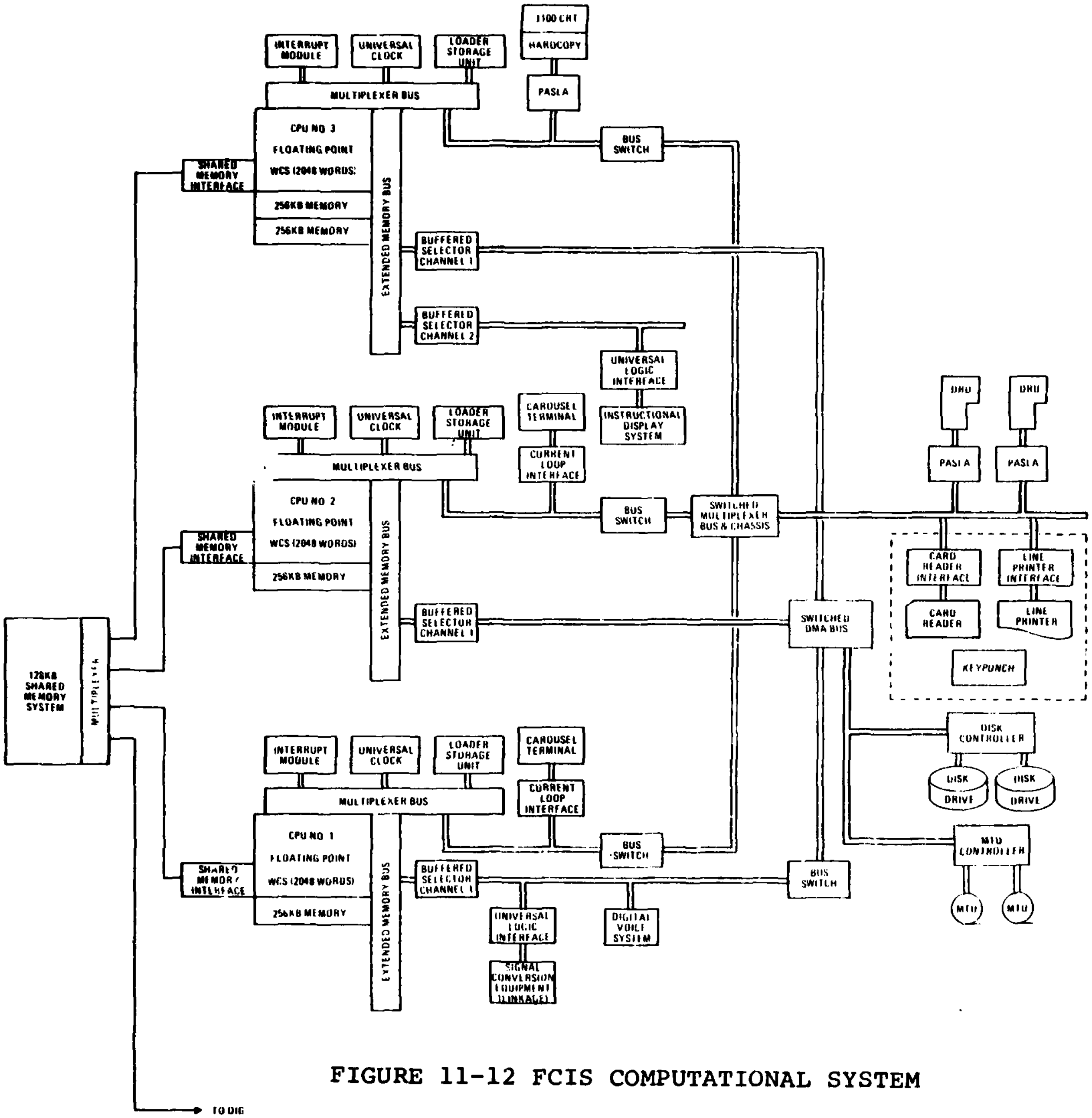

FIGURE 11-12 FCIS COMPUTATIONAL SYSTEM

A number of special devices are also required as interfaces to the computer system. These special interfaces are utilized to perform computer-related functions necessary for digital and analog communications, display processing, and instructor control.

11.2.7 Performance

11.2.7.1 Central Processors. Each central processing unit should be an Interdata 8/32 general-purpose processor, which is a high-performance, 32-bit, fully parallel processor. The CPU's have the following characteristics:

- Dual 64-bit look-ahead stacks
- Two sets of 16 general-purpose registers (each 32 bits wide)
- Direct addressing for 1,048,576 bytes of memory
- 1024 interrupt levels
- A binary display panel
- Power fail detection and automatic restart
- Privileged instruction detect
- Provision for up to 1024 auto driver channels.

11.2.7.1.1 Central Processor Options. Each central processor requires the following devices to be directly interfaced to it on the multiplexer bus:

a) Loader storage unit, with special 32-bit bootstrap for disk and card reader, as well as a watchdog timer.

b) Interrupt module, which provides 8 input interrupts and 2 output interrupts.

c) Universal clock module containing a precision interval clock which provides interrupts to the CPU with a resolution of either 1, 10, or 100 microseconds.

d) Hexadecimal display panel which includes an advanced hexadecimal light-emitting diode (LED) readout and hexadecimal input keyboard. It also provides a key-operated on/off/lockout switch.

11.2.7.1.2 Processor Enhancements

a) Writeable Control Store - A writeable control store (WCS) should be provided in each CPU to improve performance while executing highly repetitious calculations such as the standard library subroutines. The following characteristics are provided:

   o Type of memory: high-speed bipolar

   o Memory access time: 1.0 microseconds

   o Size of memory: 2048 x 32-bit words

   o Added instructions to 8/32 instruction set

      - Write Control Store (privileged)

      - Read Control Store (privileged)

      - Enter Control Store

      - Branch to Control Store (privileged)

b) High-Performance Floating-Point Arithmetic Unit - A high-performance floating-point arithmetic unit should be provided in each CPU to allow efficient execution of the FORTRAN-generated arithmetic statements. The floating-point unit provides LOAD, STORE, and COMPARE instructions as well as the standard floating-point arithmetic instructions of ADD, SUBTRACT, MULTIPLY and DIVIDE. The operands may be either single (32-bit) or double (64-bit) precision quantities and separate registers are utilized for the different types of precision. The floating-point unit also has additional instructions to convert from fixed-point to floating-point representation and vice versa. The complete instruction set added by the high-performance floating point unit and the minimum execution times for the instructions are given in Table 11-10.

11.2.7.2 Memory Systems

11.2.7.2.1 Private Memory. Each central processor in the system should be configured with sufficient private memory to perform the real-time computations efficiently. The memory system should have the following characteristics:

- o Core memory

- o 750-nanosecond cycle time

TABLE 11-10 INSTRUCTION SET

INSTRUCTION	EXECUTION TIME (MICROSECONDS)	
	Single-Precision	Double-Precision
LOAD FLOATING POINT	1.39	2.91/3.28
LOAD FLOATING POINT REGISTER	1.04	1.04
LOAD FLOATING POINT MULTIPLE	3.57 + 1.34N	3.69 + 2.19N
STORE FLOATING POINT	2.23/2.60	2.75/2.81
STORE FLOATING POINT MULTIPLE	3.59 + 0.90N	4.50 + 1.80N
ADD FLOATING POINT	1.82	3.38/3.75
ADD FLOATING POINT REGISTER	1.00	1.04
SUBTRACT FLOATING POINT	1.82	3.38/3.75
SUBTRACT FLOATING POINT REGISTER	1.00	1.04
MULTIPLY FLOATING POINT	2.50	4.90/5.30
MULTIPLY FLOATING POINT REGISTER	1.75	2.50
DIVIDE FLOATING POINT	4.45	9.20/9.65
DIVIDE FLOATING POINT REGISTER	3.60	6.70
COMPARE FLOATING POINT	1.45	3.00/3.40
COMPARE FLOATING POINT REGISTER	0.60	0.60
FIX REGISTER	5.35	8.10
FLOAT REGISTER	2.00	2.00

NOTE: THE FOLLOWING CONDITIONS WILL CAUSE THE EXECUTION TIMES TO BE INCREASED:

- o NORMALIZE RESULT (ADD, SUBTRACT, MULTIPLY, DIVIDE, LOAD) - 100 NANOSECONDS PER HEXADECIMAL DIGIT SHIFTED.
- o EQUALIZE EXPONENTS (ADD, SUBTRACT) - 100 NANOSECONDS PER HEXADECIMAL DIGIT SHIFTED.
- o ALTERNATE 1'S AND 0'S (MULTIPLY).
- o POSITION OF INSTRUCTION IN LOOK-AHEAD STACK - CAN INCREASE TIME BY 400 NS MAX, IF IT CAUSES STACK TO REFILL.

- Parity error detection
- Minimum increment: 131,072 bytes
- Maximum memory size: 1,048,576 bytes
- Interleaving method: 4-way

11.2.7.2.2 Shared Memory. In addition to the private memory defined above, each CPU will be directly interfaced to a shared memory system. The memory boards utilized in the shared memory should be identical to the private memory specified above. In addition, the shared memory system should have the following characteristics:

- Throughput rate: 10 megabytes/second
- Maximum number of ports: 16
- Interleaving method: Halfword interleaved
- Propagation delay caused by multiplexing: 700 ns (read), 0 ns (write)

11.2.7.3 Shared Peripherals

11.2.7.3.1 Bus Switches. Input/output bus switches should be provided as a convenienc and inexpensive means of enabling multiple processor access to a common I/O bus. The bus switches should operate in the following manner:

1) The common I/O bus should be idle unless a switch has been requested and has been granted bus control

2) If the bus is busy, requests for access from other switches should be registered within the switch for response as soon as the bus is released.

3) A master/slave option should be implemented allowing one designated switch in the multiple-processor configuration to assert unqualified control over the shared bus, terminating transfer to/from the common bus by slaves.

4) The switches should be solid-state and have a control panel which allows a manual override control for up to six processors sharing a single common switch bus.

Two sets of bus switches should be provided, with one set being dedicated to the selector channel for the disk and the second set being utilized for the devices interfaced to the multiplexer bus, as defined in the following paragraphs.

11.2.7.3.2 Shared Selector Channel Peripherals

a) Disk Drive and Controller - A 3330-type disk drive and controller subsystem should be provided to meet the basic requirements for on-line mass data storage. The controller provided should have the capability of controlling up to four disk drives. The disk drive should have the following characteristics:

- o Transfer rate: 1,200,000 bytes per second
- o Bit density: nominal 6000 bits per inch
- o Track density: 384 tracks per inch
- o Cylinders: 823
- o Tracks per cylinder: 5
- o Sectors per track: 64
- o Bytes per sector: 256
- o Formatted capacity: 67,200,000 bytes
- o Track-to-track switching time: 7 milliseconds
- o Maximum track seek time: 55 ms
- o Average access time: 30 ms
- o Maximum rotational latency: 16.67 ms
- o Average rotational latency: 8.33 ms
- o Write protect (selectable)

b) Backup Disk Drive - Another disk drive should be interfaced into the controller of the disk so that in the event of a failure of the primary disk it shall be possible to continue training with a minimum of interruption. This drive should be functionally interchangeable with the primary disk drive.

c) <u>MTU Controller and MTU's</u> - Two identical magnetic tape units should be provided, arranged as two 1 x 4 controllers and one primary drive, plus one expansion drive, with the following characteristics:

- o 800 and 1600 bits per inch
- o 75 inches per second for read and write
- o 200 inches per second rewind
- o Read and write capability
- o Parity checking with corrective action
- o The proposed configuration allows two units to operate concurrently
- o 10.5 inch reels
- o Recorded tape formats are IBM standard unlabeled ASCII or EBCDIC formats which will interchange with the CYBER 74 in the appropriate I/O modes.
- o Binary and ANSI II character recording modes.

11.2.7.3.3 Shared Multiplexer Bus Peripherals

a) Carousel 30 Computer Terminal - Carousel 30 terminals should be provided to function as operator consoles to the Interdata operating system (OS-32MT). It will be interfaced to the multiplexer bus via a current loop interface. This equipment should have the following characteristics:

Print Speed: 30 characters per second

Character Set: 64 character ASCII

Print Line: 80 characters

Current Loop Interface: 20 mA

External Cable: Provided

50Hz Operation: Provided

Acoustic Cover: Provided

Pedestal Cover: Provided

Basic Supply Kit: 6 ribbon cartridges and 3 print cups

b) CRT Terminal, Keyboard, Hardcopy Unit -

Terminal and Keyboard - The CRT terminal and keyboard should be an Interdata Model 1100 equivalent and should meet the following specifications:

Number of Lines: 24

Characters Per Line: 80

Character Generation: 9 x 12 dot matrix

Character Code: 128 ASCII

Refresh Rate: Line Frequency (50 or 60Hz)

Scan Method: Raster

Phosphor: P4 White

Cursor: Reverse video block

Data Entry: Cursor-determined or bottom line scroll upward

Communication Interface: RS232C/CCITT-V24 or 20 mA current loop

Transmission Mode: Half or full duplex (switch selectable)

Baud Rates: 75, 110, 200, 300, 600, 1200, 1800, 2400, 4800, 7200, 9600, (switch selectable)

Character Format: 10 or 11 bits

Parity: Odd, Even, Mark, Space (switch selectable)

Stop Bits: One or Two (switch selectable)

Printer Interface: RS232C or 20 mA current loop (optional). Baud rates of 75, 110, 200, 300, 600, 1200, 1800, 2400, 4800, 7200 and 9600

Dimensions

Height: 19.5 inches (49.5 cm)

Width: 21.5 inches (54.6 cm)

Depth: 23.5 inches (59.7 cm)

Weight: 50 pounds (22.7 kg) (shipping)

Power: 115 VAC ±10%, 60 Hz
230 VAC ±10%, 50 Hz

Environment

Temperature: 0 to 45°C operating

Humidity: 0 to 80%, no condensation

Hardcopy Unit - The hardcopy unit should be a Hazeltine Thermal Printer Unit or equivalent meeting the following specifications:

Print Speeds: 10 - 30 cps

Carriage Width (Cols.): 80

Paper Feed: Friction

Interface: Operates in conjunction with commercially available video display terminals

Controls: On-line, line feed, carriage return, power on/off

Printable Characters: 64 USASCII, upper case

Paper Size and Type: 8½"

Ribbon: None

Spacing: Horiz: 10 characters per inch;
Vertical: 6 lines per inch

Power: Single Phase, 120 VAC, 60 Hz; 2 amps

Size: 6 in. H; 16 in. D. W

c) Digital Remote Control Units

1) Two Termiflex Corporation HT/4 terminals and appropriate software should be provided. These terminals are approximately 7 inches high x 4½ inches wide and 2 inches in depth and weigh approximately 13 ounces. The front panel layout is shown in Figure 11-13.

2) These portable units should connect into jacks which will be located in the crew station areas. The DRU shall be interfaced to the computer complex via standard RS232 interfaces on the shared multiplex bus.

3) No physical modifications of the devices should be necessary; however, different key nomenclature should be applied to the function keys, located on the bottom row.

4) The expanded keyboard entry capability should provide a full set of alphanumeric key-ins as well as the special control keys, thereby providing a full message capability such as that found on a teletypewriter.

5) The LED display readout display should consist of two rows of 12 characters each and should be used to display either the physical core address or the symbolic name of a variable as well as its numerical value.

DRU Operational Description

1) The DRU should function as a real-time debug program which processes inputs from the function switches and keyboard and produces the displays and alarm indications consistent with the capabilities described in (TBD) . through (TBD).

2) The program should validate the input data and determine, by scanning the list of input characters, the function to be performed. The input string should be considered terminated when all the required predetermined data has been received. A continuous update of the data displayed will be provided upon detection of the "repeat" function signal having been received.

3) The data display should be updated and the display refreshed at the rate of 1200 baud.

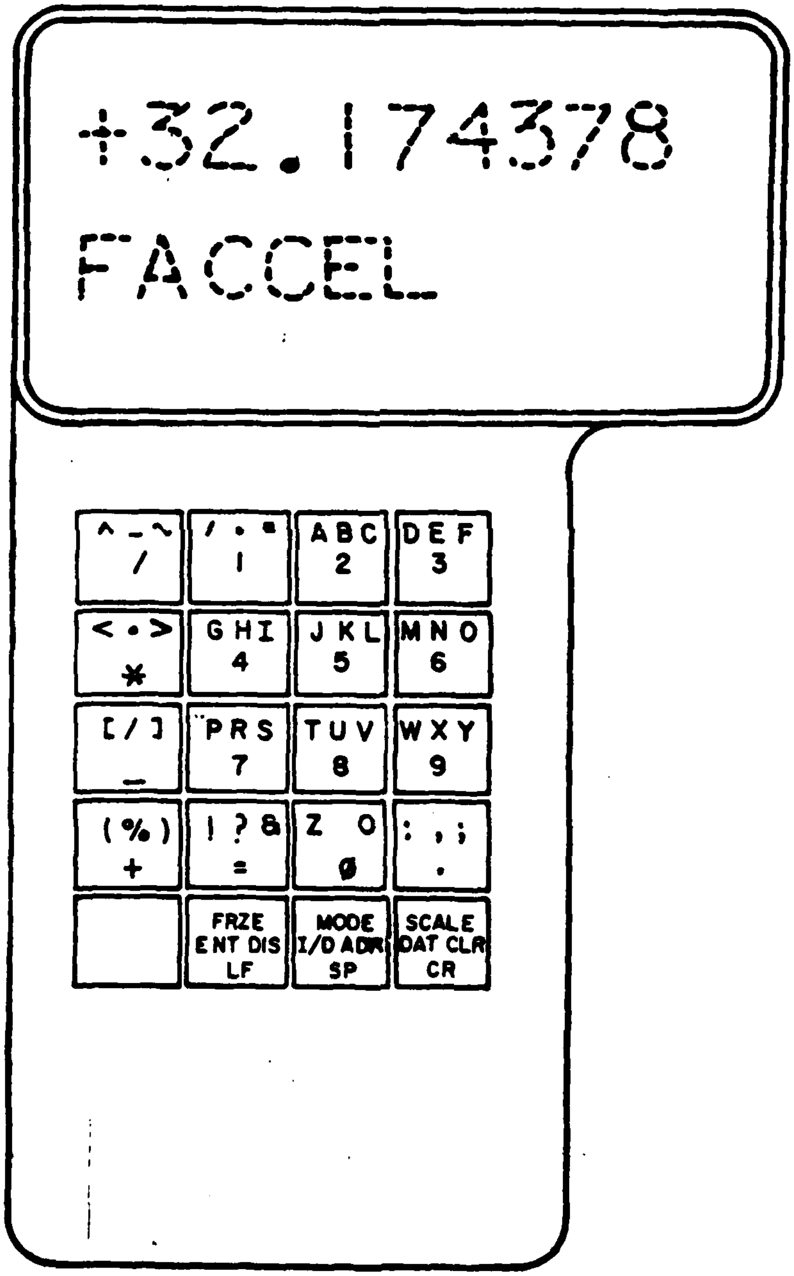

Figure 11-13 Digital Remote Control Unit

4) In addition to the value displayed, either the hexadecimal machine location (address) or the symbolic name of the variable taken from the symbol dictionary should appear in the LED display.

5) The real-time executive program should also interface with the DRU program module to provide the capability for the display of cycle and frame timing information as well as other significant messages relating to the status of the real-time simulation processing.

Function Switches - The principal function switches will operate in the manner described below in any mode:

Switch Name	Function
ENT (ENTER)	Initiates loading of keyboard data as input to one of four other functions: Mode, Address, Data or Scale. The keyboard data is loaded into the selected function register. Initiates updating of the display, and upon validation initiates storage of data into the selected memory address.
FRZE (FREEZE)	Freezes the simulation problem while allowing the DRU to alter and read out the contents of any register/memory.
DIS (DISPLAY)	Initiates display of the selected function.
I/D (INCREMENT/DECREMENT)	Increments or decrements the address prior to entering or displaying data for the new address.
RPT (REPEAT)	Provide a continuous update of value displayed.

The remaining five function switches are used to select the function register into which the keyboard data is to be loaded, or the function which is to be displayed.

The significance of the keyboard is described below:

Switch	Data Entry	Function
MODE (MODE)	00	Not used (ignored)
	01	Register Monitor
	02	Monitor Data, Hexadecimal Format
	03	Monitor Data, Decimal Format
	04	Monitor Boolean State
	10	Not used (ignored)
	11	CPU 1
	12	CPU 2
	20	Increment
	21	Decrement
ADR (ADDRESS)	1 digit	Register Address (Hexadecimal Format)
	2 or more digits	Memory Address (Hexadecimal Format)
	3-6 charac-ters	Symbolic name of variable
DAT (DATA)	40	Not used
	41 (8 di-gits)	Decimal in floating point stored in memory
	42 (8 di-gits)	Hexidecimal data to be stored in memory
	43 (8 di-gits)	Decimal data to be scaled and con-verted to hexidecimal and stored in memory
	44 (8 di-gits)	Floating decimal displayed
SCALE (SCALE)	50-53	Not used
	54($\pm$2 di-gits)	Floating decimal used to scale data to be stored in memory or to rescale data read from memory. All floating point data entered is normalized prior to storage in memory.
CLR (CLEAR)	(Ignored)	Clears display, uncomputed entries.

Keyboard

1) Ten digits are provided in the keyboard register. Depressing the CLR function sets the keyboard register to all zeros. As each key (except the decimal point) is depressed, the corresponding digit (0 through F) is loaded into the upper least significant digit (LSD) of the display, shifting the contents of the display register one digit to the left (the digit in the most significant digit location being shifted out). In the decimal mode the most significant digit (MSD) represents the sign.

2) The decimal point key is effective only when entering data or scale if the decimal mode has been selected. In this case the decimal point will take effect at the location where it is loaded.

3) When data has been entered into the keyboard register to the satisfaction of the operator, depressing the "ENTER" switch will load the contents of the keyboard register into one of four internal function registers (Mode, Address, Data or Scale).

Displays - The displays should consist of two 10-character LED readouts, capable of displaying the full set of 128 ASCII characters:

1) Numeric

a) The upper 10-digit readout should be capable of displaying the data in hexadecimal, octal, and decimal formats. The largest number that will be displayed in hexadecimal format is "FFFFFFFF". In address mode the four digits on the left (MSD's) shall be blanked and the hexadecimal data will be displayed in the remaining six digits on the right.

b) The largest number that can be displayed in decimal format is "+99999999". In this case, all ten readouts are active, with the MSD representing a "+" or a "-". The decimal point should also be displayed in one of ten places, after the sign, between digits, or after the last digit.

2) Alphabetic - Alphabetic character data should be displayed in the lower 12-digit LED display. The messages to be displayed include:

FREEZE - When the freeze function has been entered.

INVALID - Upon detection of a syntactical input error.

TRUE or FALSE - Upon the display of a boolean variable (Mode 04).

ABORT - Upon detection of a CPU abort situation by the executive program.

3) Message Bell - The HT/4 should produce an audible beep when any of the following conditions occur:

a) Depressing a key when not clear to send.

b) Attempting to generate an improper character.

AD-A091 427 SINGER CO BINGHAMTON NY LINK DIV F/G 19/3
DESIGN DEFINITION STUDY REPORT. FULL CREW INTERACTION SIMULATOR--ETC
JUN 78 N61339-77-C-0185
UNCLASSIFIED LR-895-VOL-6 NAVTRAEQUIPC-77-C-0185-000 NL

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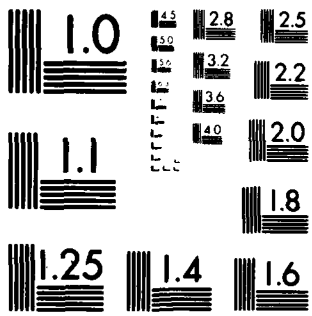

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

4) Support Peripherals - The following devices should be provided with the FCIS LM to allow software support functions:

   - o A 600 (min)-cpm card reader and interface controller
   - o A 600-lpm line printer and controller
   - o An IBM Model 029C interpreting keypunch

11.2.7.4 Special Function Interfaces.

a) Interdata Universal Logic Interfaces (ULI) should be utilized to provide the interface between the computer complex and the following hardware:

   1) Instructional Display System

   2) Signal Conversion Equipment

   The Interdata ULI contains a processor interface including address selection, interrupt control, and data buffer. The interface is factory-designed as a totally functional 16-bit input/output module with the capability to output 16 latched lines, four control lines, and an initialize line. In addition, 16 independent TTL-compatible input lines are included that are complemented with 8 status lines and an interrupt line.

   The interface should be used as an I/O extension of the selector channel and should be designed to transfer data at rates up to 1,900,000 bytes per second.

   The custom logic design portion of the interface allows for up to 77 integrated circuits using either 14- or 16-pin dual in-line IC's. The custom logic design portion for each of the required interfaces will be incorporated on the ULI, resulting in several unique ULI designs all based on the same system module. The function provided by the first six interfaces are explained elsewhere in this specification. The SCE is described in paragraph 11.2.7.5.

b) Visual System Interface - The visual system (DIG) should be interfaced via the Interdata 8/32 shared memory. Either a direct interface (multiprocessor) or a processor/processor interface (multicomputer) is acceptable because of the very low data interchange requirement (less than 25000 bytes per second).

11.2.7.5 Signal Conversion Equipment

a) A Link-built signal conversion equipment (SCE) system can be provided to interface the computer complex with the FCIS-LM crew station hardware. It shall provide for discrete inputs, discrete outputs, analog inputs, and analog outputs to and from the computer complex.

b) A functional block diagram of the interface equipment is shown in Figure 11-14. The interface equipment will consist of a computer interface, a master controller, several subcontrollers, and the required number of interface electronic cards.

c) The interface equipment I/O data should be arranged in data pools resident in the shared memory system. Once every 33 milliseconds, the host computer complex will, thus, cause an interchange of information between the master controller's memory system and the host computer's memory system.

d) The DMA interface between the master controller and the host computer memory should perform the necessary conversions between the formats of the data in the master controller and the data in the memory of the host computer system, according to Table 11-11.

e) In the cases where the conversion is not done in the DMA interface, software routines should be utilized to convert the data into the required formats.

Table 11-12 delineates signal conversion equipment requirements and provisions for the FCIS Instructor Station, Fighting Station, and Driver Station. For the SCE provided, including spare in excess of 25%, and with all I/O occurring at a 30 Hertz rate, a total data transfer of 260 Kbits per second is anticipated. This is well within the nominal SCE transfer rate of 1 Megabit per second.

TABLE 11-11 DMA DATA FORMAT CONVERSIONS

	Format in Master Controller	Format in Host Computer	Converted
Discrete Inputs	Single bit in 16-bit word	32-bit word	No
Discrete Outputs	Single bit in 16-bit word	32-bit word	Yes
Analog Inputs	16-bit fixed-point number	32-bit floating-point number	No
Analog Outputs	16-bit fixed-point number	32-bit floating-point number	Yes

TABLE 11-12

SCE REQUIREMENTS

	AI	DI	AO	LO
Requirement				
IES	4	47	--	25
Fighting Station	10	75	20	64
Driver Station	9	28	35	20
SUBTOTAL	23	150	55	109
SPARE	6	38	14	28
TOTAL	29	188	69	137
Provision				
IES	7	64	8	64
Fighting Station	28	256	32	192
Driver Station	28	64	32	128
TOTAL	63	384	72	384
I/O Transfers per second	1890	720*	2160	11520

* 16-bit packed words

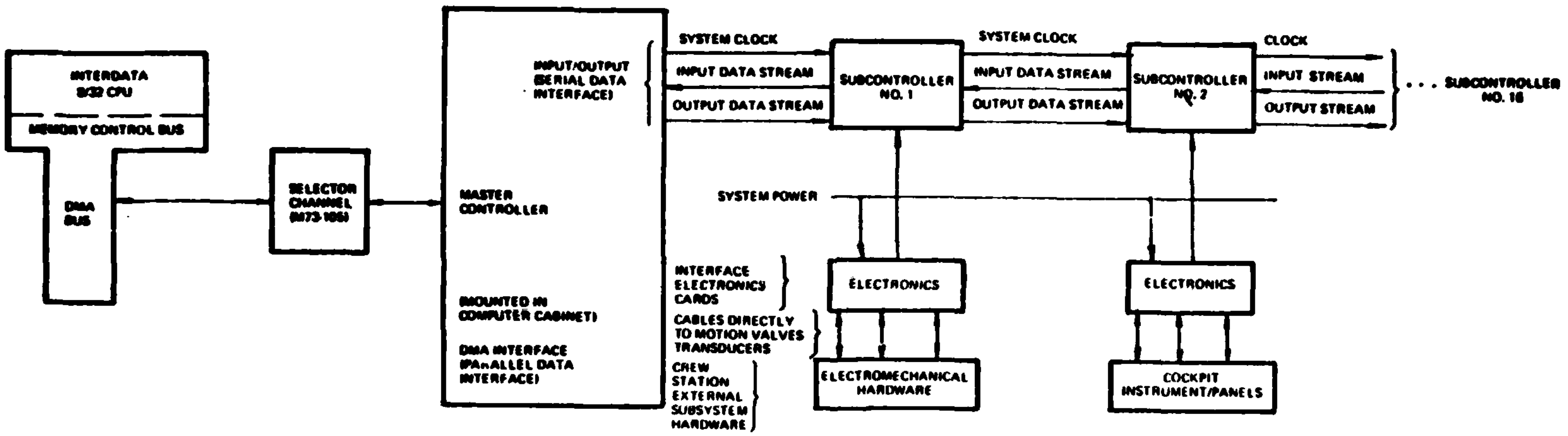

Figure 11-14 Real-Time Interface System Block Diagram

11.2.7.5.1 Master Controller Functions. The master controller will be the central controller for the signal conversion (interface) equipment system and should provide:

a) Communication with the computer I/O data memory via the DMA channel. The DMA provides word-serial, bit-parallel, two-way communication with the computer I/O data memory via a standard interface.

b) Parallel-to-serial data conversion for the output data stream.

c) Serial-to-parallel data conversion for the input data stream.

d) Address translation from computer memory I/O data address to interface electronics and address.

e) Synchronizing clocks for the subcontroller and interface electronics cards.

f) Message control to the subcontroller and interface electronics cards.

g) Control for achieving the closed-loop interface equipment test.

11.2.7.5.2 Subcontroller Card Functions

a) The subcontrollers should provide the capability for reliable serial data communication between the master controller and the interface electronics cards. A bit-serial data transmission stream will be utilized for transmitting output information (analog outputs, discrete outputs) from the master controller to the interface electronics card (output data stream). A separate bit-serial data transmission stream will be utilized for transmitting input information (analog inputs, discrete inputs) from the interface electronics to the master controller (input data stream).

b) The subcontrollers should also provide the following functions:

   1) Word framing

   2) Input output data stream coordination

   3) Block address identification functions

   4) Transmission line signal boost functions

c) In each subcontroller provided, it should be possible to mount up to 16 interface electronics cards.

11.2.7.5.3 Interface Electronics Card Functions

a) The interface electronics cards should have three interface ports which operate as follows:

   1) The output port should connect directly to the simulated instrument, switches, etc.

   2) The power port should connect to all simulator power buses required to operate the instruments and the circuitry on the interface electronics cards.

   3) The I/O data port should connect to the subcontroller and pass all the digital data involved to and from the subcontroller.

b) The interface electronics cards should also incorporate closed-loop test circuitry to connect appropriate data conversion modules (including associated multiplex data steering gates and level translators) to the I/O data port for the closed-loop test checkout of the interface system.

c) The following capabilities should be provided on the interface electronics cards as needed:

   1) Digital-to-analog conversion: 11 bits (10 magnitude bits plus sign bit) with a ±10-volt output range

   2) Analog-to-digital conversion: 12 bits output with a ±10-volt input range.

   3) Discrete inputs: capable of accepting:

      o +5 vdc signal

      o +28 vdc signal

      o Relay or digital ground with 1 mA sinking capability

   4) Discrete outputs:

      o Digital ground with 10 mA current sink and 28 vdc standoff

      o Relay ground with 300 mA current sink and 28 vdc standoff

11.2.8 <u>FCIS-LM Computer Program Development</u>. The FCIS-LM computer program system should be designed as a group of modular subprograms. The software to be provided includes the real-time operational programs required for normal trainer operation, and off-line programs for simulation support, computer system support, maintenance and test, calibration test, and utility programs.

11.2.8.1 Program Module Architecture. Top-down programming concepts should be used in the design and development of software model programs. Top-down programming requires that coding, compiling, checkout, and integration of program modules and submodules be performed in levels, i.e., Level 1 is produced and verified before Level 2 is started, etc. The primary difference between this design procedure and procedures commonly used in software development is that development phases (levels) descend instead of ascend, i.e., common practice employs bottom-up development. Top-down programming requires that each successive model be identified and the contents of the programs at that level be established along with all interfaces to other levels within the module. Each module will then be further subdivided into submodules and, finally, into mathematical/data conversion library subroutines and module variable and constant data pools.

11.2.8.2 Program Language. The higher order language considered as most desirable for the FCIS-LM is the FORTRAN language. As much real-time programming as possible should be done in FORTRAN. The only allowable exceptions are the following:

a) Portions of the real-time executive

b) Device Handlers for I/O Devices

c) Subroutine libraries, including writeable control store portions

d) Portions of Record/Playback/Demonstration

e) Visual interface (to allow bit packing)

11.2.8.3 Real-Time Computer Programs ~~Requirements.~~ Real-time computer programs include those considered as executive programs, synchronous application programs which simulate the vehicle dynamics and vehicle subsystems, motion system programs, and advanced training programs.

A table providing the estimated real-time computer time and memory requirements for the FCIS-LM was shown in Table 11-6.

These estimates have been used as a basis for determining the FCIS computation system hardware requirements.

11.2.8.3.1 Executive Programs. A set of modules are required which constitute the supervisor, or real-time executive, program.

Supervisor Program - The supervisor program will include a master control function to provide synchronization among simulation module execution, interface equipment input/output operations, frame and cycle time, verification, background activities, and intercomputer communication and synchronization. The basic timing will be controlled by a programmable real-time clock or the 60 Hz line frequency clock.

The definition of the modules to be executed in each of the computational frames, and the relative order of execution of these modules, will be fixed by a queue or list which will reside in each computer core memory. The primary supervisor module is therefore a list-driven processor which calls each simulation module in order, after a start-of-frame is defined by receipt of an external interrupt.

Other processing will be provided by modules within the supervisor program group. Significant processing provided on an on-demand basis includes executive trap processing, basic real-time/non-real-time mode control, and control of operator console input/output as related to supervisor program control.

The real-time executive will control the execution of the simulation software. It will consist of a single task and will:

a) Be interrupted by interrupt handlers within the same task at specified time intervals for determining out-of-time conditions and starting hardware functions on a periodic basis.

b) Control execution of simulation modules

c) Control simulation mode from the master CPU

d) Perform frame and cycle timing

e) Process error messages

f) Schedule synchronous and asynchronous tasks

g) Allow modules to activate or deactivate other modules

h) Allow interrupts to enable the scheduling of on-demand modules

i) Keep all computers in a multiprocessor complex in sync while running in an integrated (master/slave) state.

I/O requests are initiated via subroutines. This will permit user software to be written with I/O requests that are transparent to the actual I/O driver requests.

The capability will be provided to reserve a portion of each frame for background processing. Background processing will reside in the spare time and memory within the simulation complex.

Overlay Loader - Overlays will be supported by the supervisor programming system. Support software will be used to define the overlay structure and will build the task with overlays. These overlay structures will be capable of dealing with code or data.

Slave Real-Time Monitor - A slave real-time monitor will be developed to run in the slave computers in the multiprocessor complex. It will perform basically the same function as the executive in the master computer. This will allow the development of one set of real-time utility programs for both master and slave computers. The size will be kept to a minimum and the program will be coded in assembler language.

The functions of the slave real-time monitor will be:

a) Limited task switching - multiple tasks will be allowed only in foreground with no background.

b) Intercept all disk I/O requests and route them through the shared memory of the master computer.

c) Capability of adding special I/O drivers by same means used by the vendor's real-time monitor.

Math Library - A library of mathematical procedures will be maintained under the non-real-time disk operating system. A numerical integration routine, together with such standard procedures as limits, functions interpolation, and trigonometric functions, will be included. The system generation software will automatically include a single copy of each required routine and perform the necessary linkage resolution at generation time. Thus, the real-time software will include a single copy of each referenced routine. Calling conventions will be compatible with FORTRAN and uniform between routines.

I/O Programs - Handler subroutines will be provided for all devices used in the real-time simulation environment, including signal conversion equipment, operator's console, instructor station CRT/keyboard, magnetic disk, magnetic tape, and real-time clock.

These I/O handlers may be broken into three basic types:

a) The signal conversion equipment handler, which is a list-driven subroutine wherein the receipt of each I/O-complete interrupt initiates start of a new I/O transfer, and the list of different transfers to be affected during a frame is preassembled and constant during the entire simulation.

b) The moving-head disk handler, in which successive requests for I/O are queued in a priority code order, and receipt of an I/O-complete interrupt,causes immediate handling of the next request in the queue, if one exists.

c) All other peripheral handlers, which handle I/O requests on a one-at-a-time basis.

Real-Time Interface Equipment Diagnostic Program (Fault Isolation System Support - A real-time closed-loop simulator linkage (interface) test will be provided to locate and isolate failures in the signal conversion equipment (SCE). The program will perform an automatic checkout of the interconnection between the computer and the simulator instrumentation. The diagnostic will reside on disk and tape and will be designed to operate off-line or in real-time (background mode) as a Built-In Test Function Program.

The SCE consists of the following four basic electronic hardware components, each having its own special test routines:

a) A master controller which interfaces with the computer, performs its own processing functions, and distributes data to/from the system components.

b) The master controller output port bus,over which the data is transferred.

c) Subcontroller which provides the interface between the master controller and the actual system cards.

d) System cards which interface with the simulated systems.

Like the interface hardware, the program itself will function in a modular manner. Among the principal tests to be performed are:

1) A data pattern and addressing test of the master controller memory

2) A test of the floating-point conversion hardware.

3) A closed-loop test of individual system card performance using a group of hardware subsystems contained within the master controller. These tests include:

   a) Testing discrete inputs and digital word inputs at both logic states

   b) Testing discrete outputs and digital word outputs at both logic states.

   c) Testing analog inputs over the entire analog range for the ability to respond to a computer-controlled test value within a predetermined tolerance.

4) A test of proper functioning of the DMA channel if a failure is encountered in any of the above tests. An appropriate error message will be output on a hardcopy unit giving the type and hardware location of each failure.

11.2.8.4 Off-Line Programs. Off-line programs include:

- o Simulation support programs
- o Computer system support programs
- o Maintenance and test programs
- o Calibration test programs
- o Utility support programs

11.2.8.4.1 Simulator Support Programs.

Cycle Time Verification Programs - Programs are required to verify the operational cycle time and spare time remaining within the cycle and frame periods, and to preflight-check the simulator. These verification programs should be designed to run within the deliverable computer configuration.

Premission Check Program - A computer program is required to support the operation of the simulator in the normal procedures identified for premission check. This program should easily determine if the simulator is ready for operation. It should operate at normal iteration rates and generate a sequence of standard outputs which drive all perceivable outputs and recognize all inputs. The sequence of outputs should be cyclic, with provisions to stop the sequence at any of the standard output values. The complete premission check procedure using this program should not exceed 15 minutes. This is not intended as a calibration program, but rather as a quick system operational check.

Mission Support Programs - A mission support program for alphanumeric/graphic CRT display generation is required to operate on the FCIS computational system.

The CRT page generator should accept source input in card image format (cards or tape), perform syntax checking, generate the display skeleton (static information) and conversion attribute data (for dynamic information), and store these in the on-line loadable CRT page file. The page generator should produce a hardcopy listing of the page content, errors, and, optionally, the object data.

11.2.8.4.2 Computer Program System Support Programs. Support programs are required to facilitate computer program generation, redesign, update, modification, error correction, and other support functions. The support programs to be provided are as follows:

Operating System (OS)

a) A computer vendor-supplied real-time operating system should be used to provide a high-performance multiple task environment for batch oriented processing. The OS shall be responsible for the total programming system management. All support programs should be programmed to operate under the control of the OS and utilize the services it provides, while remaining as independent of modification to the OS as possible.

b) The real-time operating system should provide a multi-tasking environment for user-development application systems. It should be optimized to the requirements of event-driven real-time systems.

c) Program preparation and development should be supported and carried out in parallel with the operation of a real-time system.

d) The operating system should provide a flexible structure, enabling systems designers to construct systems optimized for their individual applications, based on a modular executive, intertask coordination, and control of task capabilities.

e) The interrupt handling facilities required include dynamic task priorities, task-handled traps, and real-time scheduling.

f) A data management system is required which incorporates the following features:

- Device Independence

- o Named Files and Devices

- o File and Device Protection

- o Contiguous and Chained File Structures

- o Disk Pack Interchange

g) General supervisory services, including clock and calendar facilities, character manipulation facilities, priority semaphores, and a memory manager should be provided.

h) User interfaces. Comprehensive preparation facilities should include support of assemblers, compilers, utilities, task establisher, and configuration utility program.

Peripheral Operating System

a) A complete set of standard I/O handlers are required to execute under control of the OS. These handlers may also be invoked by user programs under supervisory services provided with the real-time operating system. The drivers/handlers selected to be supplied for the FCIS computer configuration should include those to support the following devices:

- o Card Reader

- o Line Printer

- o 80-MB Disk

- o Magnetic Tape Unit

- o CRT/Keyboard

- o Hardcopy Unit

- o Real-Time Clock

b) Other special I/O interface handlers should be provided as required to be included as part of the real-time simulation executive program. These handlers should be compatible with the OS while retaining those special characteristics demanded by the simulation equipment.

Loaders, Assemblers, and Compilers

a) The loader program provided as part of the OS should be the primary processor for building the real-time simulation load. A set of job control statements should be provided to allow complete CPU-by-CPU loads to be accomplished with a minimum of operator intervention, using operating system services for file and data management.

b) To provide for automatic handling of the large number of data pool variable names anticipated and to provide automatic library call facilities, a data pool symbol dictionary, an associated file maintenance program, and an object module editor program are required. The dictionary and editor should provide an optimum environment for the loader to generate the relatively large load required (compared to most user programs which are loaded to run under the OS).

c) A bootstrap loading subroutine should be incorporated into the real-time simulation load in absolute form. Standard checksum facilities of the loader shall be used for checking the validity of the relocatable object modules. Other configuration control related features that are available as by-products of the loader should include a hardcopy output of a load map containing a list of all modules loaded, their locations in memory relative to the start of the task, all external symbols with a cross-reference to their use in the program modules and header information contained in the load file and reproduced on hardcopy, giving the time and date of the load, its revision level, and other identifying characteristics.

<u>Memory Dump</u> - A computer-vendor supplied memory dump program should be provided to output the contents of a section of memory defined by a set of address limits. The format of the dump should be selectable and include the following:

a) Binary

b) Character

c) Double-precision floating-point

d) Single-precision floating-point

e) Full-word decimal

f) Half-word decimal

g) Half-word hexadecimal

h) Full-word hexadecimal

<u>Mathematical Library</u>

a) The FORTRAN system consists of a compiler and a FORTRAN library. In addition to providing subroutines for all supervisor functions whose calls are generated by the compiler and run-time (under the operating system) diagnostic messages, this FORTRAN library should contain a set of mathematical routines that include standard FORTRAN functions as a subset. This FORTRAN system should be accessible to both real-time application programs, and verification and support programs which run under the OS.

b) The real-time simulation load should include a specially written set of mathematical subroutines, existing as one or more modules to be incorporated into the load for each CPU. These subroutines should include assembler language programs and mathematical subroutines which require less execution time than similar subroutines provided in the standard FORTRAN library package. Other subroutines should be provided for data conversion tasks which are peculiar to the real-time simulation tasks, and should also include conversions from internal memory storage formats to print and CRT terminal display formats, and conversion from keyboard formats to internal processing formats.

c) The complete set of these special mathematical and data conversion subroutines should be provided in source and relocatable object module formats, in a form which may be used for real- time simulation or operation under the OS.

Copy and Trace Routines - The following general-purpose development tools should be provided as part of the software to operate under control of the OS:

a) A background program which gives the user trace, breakpoint, and snapshot features.

b) A terminal oriented text editor which allows the user to interactively create source images for submission to the system.

c) A utility which allows the user to copy files from one device to another for peripheral conversion, reproduction or data retention.

d) Under the operating system it should be possible, using existing job control files, to copy ASCII or binary files from device to device, including disk to disk, card reader to disk, disk to printer, card reader to printer, disk to tape, tape to disk, and tape to tape.

11.2.8.4.3 Maintenance and Test Programs. Programs are required to fully test the operation of both the computational hardware system and the interface equipment. When a malfunction occurs in the computers or simulator equipment, these programs should provide information to the operator to identify and locate the malfunction. They should be capable of running with a minimum of operator intervention.

Real-Time Interface Equipment Diagnostics

a) The maintenance procedure should allow the operator to localize real-time interface errors detected during Premission Check or during training sessions. A master hardware index should be available on the disk for display on the DEBUG CRT. It shall contain the panel numbers and a brief description of each panel.

b) Three unique test cases for each panel should test all the panels' components. These tests should be automatically cycled through as many times as required or the operator should be able to specify each new test case manually. When the operator knows which panel contains the fault, he should be able to traverse the assembly tree to the desired test page.

c) After the operator locates the panel to be tested, all SCE equipment should be tested in an orderly fashion. All of the DI's, DO's, AI's and AO's should be displayed on the CRT screen with their associated documentation, including symbol, description, system drawing, linkage designation, and appropriate input position or readout value. Inputs should have the actual and expected values displayed together. Outputs should have the actual drive value and a line number for modifying the value.

Computer Diagnostics - A complete set of vendor-supplied computer diagnostics are required. These diagnostics should include but not be limited to the following:

a) Memory diagnostic

b) CPU diagnostics

c) Disk diagnostics

d) Printer diagnostics

e) Disk Formatters

f) System exercisers

g) Card reader diagnostics

h) MTU diagnostics

11.2.8.4.4 Calibration Test Programs.

a) Calibration test programs are required to check the accuracy and flow of signals, both statically and dynamically, through the full range of variables, between the computer and all signal sources and terminal points. This program should also be used to calibrate the interface equipment, displays and controls, and to determine whether the inputs provided by the simulation program are being transmitted properly to the ultimate destination.

It should initialize all signal paths (both source to computer to terminal points) to preselected values and allow monitoring of the signal and subsequent calibration at any point in the signal path where the signal can be monitored. The program should allow the operator to temporarily modify the preselected values on-line.

b) Each hardware panel should be provided with three unique test cases for the testing of all components. These should be automatically cycled through as many times as required, or the operator shall be able to specify each new test case manually. Calibration of all analog devices should be performed using prescribed values generated off-line and stored on the disk. To insure that analog instruments are driven smoothly, a ramp test shall be included in order to cycle the instruments from their minimum to maximum values in finite steps. The increments should be specified off-line and the instruments should be driven at the same execution rate as the operational modules.

11.2.8.4.5 Utility Support Programs

Assembler Program - An assembler is required. However, for the FCIS-LM, assembler language programs should be restricted to those programs requiring language facilities not available in a higher-level compiler. These programs consist mostly of interrupt and trap handlers, I/O handlers, and programs which demand a high degree of space and time optimization. The assembler should be designed to operate in conjunction with the real time operating system.

The assembler should provide flexibility in field formatting and provides a segmented object code to be used with a 32-bit processor. A fully annotated cross-reference of symbolics and error references is required. The assembler should allow 8-character alphanumeric symbols. In addition, a set of pseudo-operations should be available to the user. FORTRAN common block definition and data pool referencing should also be provided. The assembler should function in a two-pass environment with additional passes to "squeeze" (optimize) the code to produce the most efficient code possible.

FORTRAN Compiler

a) The basic programming language to be used for the FCIS simulation software should be FORTRAN. A precompiler to scan the FORTRAN source code and automatically generate external references to a common data pool is also required. In addition, a cross reference between the symbol dictionary (data pool dictionary) and the source modules should be produced and saved on the disk as part of the configuration control system.

b) The basic structure of the FORTRAN compiler should conform to ANSI FORTRAN Standard X3.9-1966. The compiler should be designed to be used with the operating system. The compiler should accept a mix of FORTRAN statements and in-line assembly code. With the FORTRAN system it should be possible to have program and data sizes up to 1 megabyte. The FORTRAN repertoire should include mixed-mode arithmetic operation, Hollerith constants, and string data statements that allow array initialization, multiple entry subroutines, and error and end-of-file returns from read-write operations. Real-time extensions are required such as bit and byte manipulation of integers, including Inclusive OR, Logical Product, Logical Complement, Exclusive OR, Logical Shift, Bit Test, Byte Load and Store, Byte Clear, and Byte Complement. The FORTRAN Library routines should be reentrant to minimize memory requirements in a real-time environment. Extensive error checks should be performed during the compilation and assembly processes with error flag notation on outputs.

Trace Routines - Software should be provided to enable the user to follow the execution of a program through the continuous listing of the location counter, the hexadecimal representation of the instructor, the instruction mnemonic, and the operands of the instruction, to the printer or other device. A branch trace should also be provided which lists the value of the location counter only if a branch instruction is encountered and taken.

Simulator Verification Programs - Software should be provided which allows the user to check out his software in the single module mode or grouped as part of a system. The operator should be able to select the module to be tested from a CRT index. The module should then be exercised through prestored test cases designed to investigate all paths through the module, including the longest path and the path using the greatest amount of CPU time. The printer should be used for hardcopying the CRT display, exception reporting, and as an X-T recorder. During this test, all debug capabilities, such as breakpoints, traces, and snapshots, should be available. Therefore, the module is in the same environment it will encounter as part of the simulator load. As an option, the capability should be provided to set input parameters before the execution of any module and to examine the results after the exception of the same or any other module, thus allowing entire systems or groups of modules to be exercised. This option should be "usable" interactively via the CRT system. It should provide a means to test a module in an integrated mode before it becomes part of the operational load.

Data Base Support Programs

a) Computer programs used to design and implement operational data bases are required to facilitate modification to these data bases. Computer programs used to perform data reduction to tabularized and/or stored data should be provided. These programs should be written for execution on the computational system configuration designed for the simulator site.

b) In order to control and maintain the data base, a Data Base Generation System (DBGS) software package should be provided. The DBGS should perform a multi-CPU complex in one symbol dictionary. This system should perform modification to the symbol dictionary by addition, deletion, or change of variable definition. Variables and I/O should be allocated into the symbol dictionary automatically by the system.

c) Listings of the symbol dictionary should be generated in alphabetic order of variables and also according to their relative location in memory. A relative listing should indicate spare locations and all overlays and equivalences of variables.

d) Configuration control information such as cross-reference listings (concordance) should be provided by the DBGS.

Simulation System Update and Modification Programs - A program should be provided to efficiently edit the source code in order to maintain CPS configuration control and to support CPS modification and update. Disk source images should be usable as the baseline source code media. This procedure should support selective module editing, compiling/assembling, linking, and testing. It should be usable by simulator maintenance technicians. The input device for change information should be the remote CRT terminal keyboard/cassette magnetic tape system.

a) Source Update - The Source Update Program (UPDATE) should allow the user to edit card image source file from the desk. The edit should be performed by control functions (insert, add, replace, delete) based on statements/numbers contained in columns 77-80 of the card image records. The following features are required:

- Automatic configuration control of header information, revision level, and change control
- Compressed storage on disk
- Error protection
- Statement level change control

- o Full listing with change indicated

- o Resequencing option

- o Edit back to any previous revision level

b) Source Modification - A source modification program (SCAN) is required to connect the user's source statements with the common data pool. It should not be necessary for the user's (programmer's) code to contain data declarations (TYPE, DATA, DIMENSION or COMMON STATEMENTS). SCAN shall search the source code, locate all variables stored or used, find definitions for these variables in the symbol dictionary, and add the required data declarations to the source prior to compilation and assembly.

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